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An Experimental Brain Missile Wound: Ascertaining Pathophysiology and Evaluating Treatments to Lower Mortality and Morbidity

Annual Report

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June Davidson, B.S.

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We have developed a laboratory model for painlessly creating a uniform brain wound in anesthetized cats and have studied blood flow in the brain before wounding and 1,30,45 and 90 minutes thereafter. By means of microspheres we have made these blood flow determinations in 35 distinct brain regions including the brain immediately adjacent to the missile track.

Blood flow transiently increased one minute after wounding where the test missile struck the brain and in contracoup areas. This increased flow resulted from loss of cerebral autoregulation and concomitant systemic arterial hypertension.

Thirty minutes after wounding blood flow transiently increased about the wound track itself.

A mild decrease in regional cerebral blood flow occurred in only 2 brain regions.

Blood flow was unaffected in most brain areas. (Keywords.)

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SUMMARY

These experiments are the first to delineate regional cerebral blood flow after a missile wound to the brain. Two basic patterns of blood flow were discerned. About 40% of cats developed significant intracranial clots after being wounded. These animals had high intracranial pressures, low cerebral perfusion pressures and a steadily diminishing cerebral blood flow both regionally and totally. In this group brain blood flow fell into the range where cellular homeostatic and energy mechanisms would fail and cell death would be expected.

Sixty percent of brain wounded cats did not have significant post wounding intracerebral clots; these cats had lower intracranial pressures and higher cerebral perfusion pressures. Among these cats 3 types of regional cerebral blood flow responses were seen after wounding.

1) In the area of missile impact and in contracoup area there was an early (1 minute) post wounding increase in cerebral blood flow caused by an increase in mean arterial pressure.

2) Thirty minutes after wounding cerebral vascular resistance significantly decreased about the wound track. Cerebral blood flow in this region concomitantly increased.

3) A mild decrease in cerebral blood flow occurred in only 2 brain areas.

In many brain areas blood flow was unaffected by the missile wound.

These experiments suggest that among animals which develop high post wounding intracranial pressures and low cerebral perfusion pressures- usually associated with intracerebral clots- cerebral ischemia is global, severe and probably fatal. Animals which do not have high post wounding intracranial pressures and, hence, maintain higher cerebral perfusion pressures early after wounding do not develop cerebral ischemia during the first 90 minutes after missile injury, even about the wound track itself.

FOREWORD

In conducting the research described in this report, the investigators adhered to the "Guide for the Care and Use of Laboratory Animals", prepared by the Committee on Care and Use of Laboratory Animals of the Institute of Laboratory Animal Resources, National Research Council (DHEW Publication No. (NIH) 86-23, Revised 1985).

The experiments presented in this report were performed by H. Carson McKowen, M.D. and J. Bryan Farrell, B.S.

This manuscript was typed by Mrs. Elizabeth P. Hulbert

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REGIONAL CEREBRAL BLOOD FLOW FOLLOWING A MISSILE WOUND TO THE BRAIN

Background

Adequate blood flow is a prerequisite to normal neural function. In awake monkeys and humans cerebral blood flow (CBF) averages about 50ml/100gm brain/min. Reduction of CBF causes a gradual deterioration of neural-glial function: electrical abnormalities appear if CBF falls below 20ml/100gm brain/min, electrical failure is complete when CBF falls to 8-15ml 100gm/min, and extracellular potassium increases when CBF reaches about 5ml/100gm brain/min indicating that ischemia has affected mechanisms providing normal cellular ionic concentration. Prolonged ischemia my lead to the failure of cellular energy mechanisms and cell death. (1) (2)

Our laboratory is currently devoted to an in-depth study of the pathophysiology of brain wounding. We have been able to find only two prior investigations of CBF following a missile wound to the brain.(3,4) One investigator utilized dogs and another monkeys and each determined cerebral hemisphere flow by (185)Xenon washout. Both observed a significant CBF reduction after wounding. Possibly, therefore, concomitant cerebral ischemia may play a part in observed neurologic deficits following a missile wound to the brain. Because of the importance of blood flow for the maintenance of neural function and the above suggestive findings, we decided to investigate regional cerebral blood flow following a missile wound to the feline brain by microspheres labelled with either (46)Sc, (95)Nb, (103)Ru, (113)Sn, or (153) Gd. The microsphere technique is a well accepted method of studying regional blood flows.

Method

Our basic technique has been described in detail in prior reports (see Annual Final Report for Contract DAMD17-83-C-3145, 10 February 1987). Briefly, unselected 3.0 to 5.5kg cats were anesthetized with intraperitoneal and intravenous pentabarbital (30mg/kg) and then intubated endotracheally. Through bilateral groin incisions the following lines were placed: 1) via the right femoral artery a pig-tailed PE 60 catheter into the left ventricle of the heart for microsphere injections; 2) a left femoral artery cannula for blood pressure recording and arterial blood sampling; 3) a femoral vein cannula for anesthetic administration. Both brachial arteries were also catheterized for reference sample blood withdrawals.

After cannulations the cats were placed in a stereotaxic frame, paralyzed with 30mg of gallamine triethiodide intravenously and placed on a respirator. End expiratory CO_2 was monitored continually and blood gases and pH maintained constant by respirator adjustments and intravenous bicarbonate administration.

Through a midline scalp incision the anterior wall of the right frontal sinus was removed and a left parietal burr hole made for insertion of an epidural pressure transducer secured with methylmethacrylate which also sealed the burr hole.

Next, a microsphere injection was made and a reference sample of blood withdrawn for measurement of a control CBF. After ensuring an adequate level of anesthesia the animals were painlessly wounded in the right cerebral hemisphere with a 2mm, 0.31mg steel sphere at either 0.9, 1.4, or 2.4 Joules. Blood flow determinations were made 1,30,60 and 90 minutes after wounding by the injection over 90 seconds of 1.4 to 2.0×10^6 microspheres suspended in 0.4 ml of fluid containing Tween 80. Reference blood samples were withdrawn from each brachial artery at 0.61ml/min by means of a Harvard pump. After withdrawal, reference blood specimens were immediately placed into tared counting bottles for counting.

At the end of each experiment the cats were painlessly sacrificed by barbituate overdose and exsanguination. Brains were fixed by intracardiac perfusion with 10% buffered formalin, removed and subsequently sectioned into 32 regions which were placed into tared vials for microsphere counting. Figure 1 indicates how the cerebral hemispheres were sectioned for regional blood flows determinations.

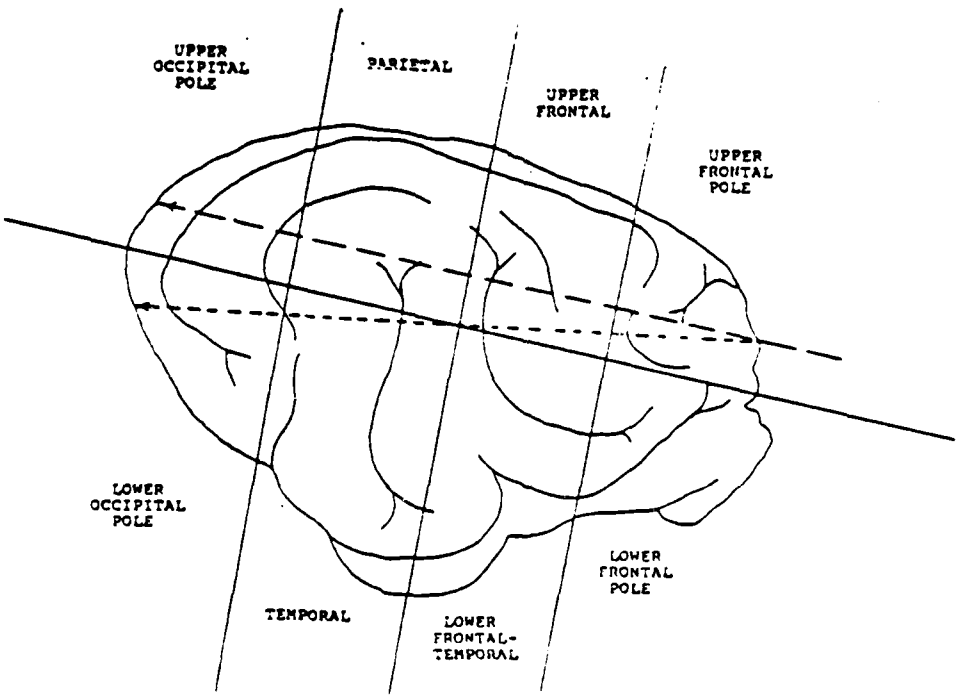


Figure 1: Right lateral view of cat's cerebral hemisphere showing sectioning scheme. Upper large dashed line indicates usual missile trajectory. Lower small dashed line indicates less frequent trajectory.

After counting these distinct brain regions, the right (wounded) cerebral hemisphere was reassembled and 3 concentric rings were cored out about the missile track, figure 2.

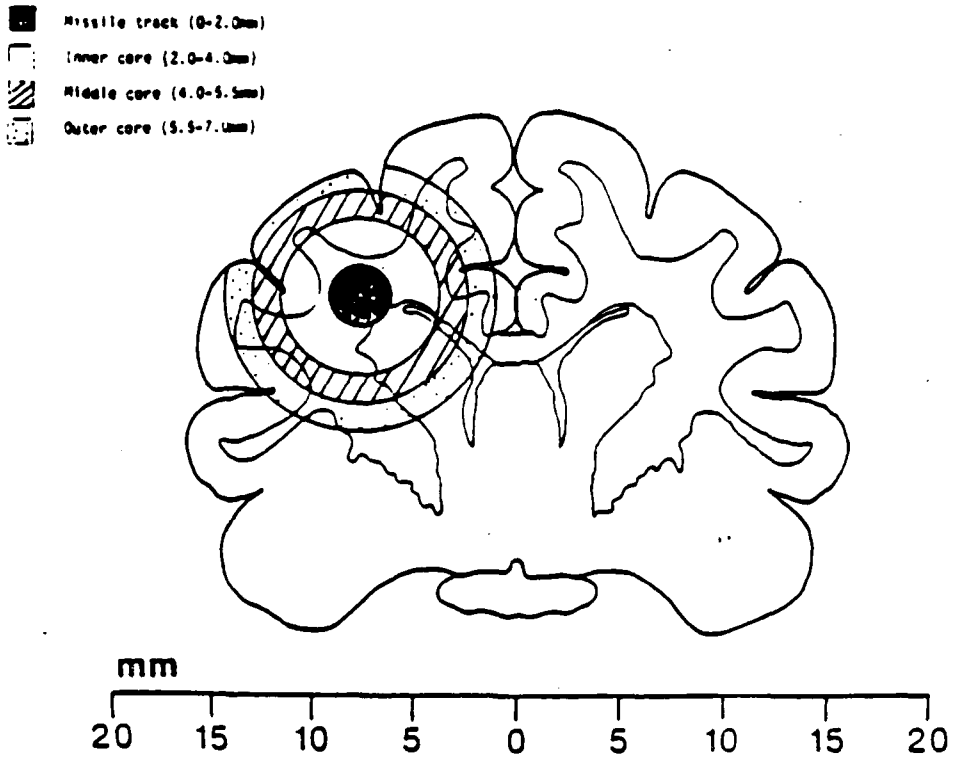


Figure 2: Coronal section of brain showing missile track and concentric cores outward from track.

The usual wound track measured 2-4mm in diameter. The "inner" core extended 2.0 to 4.0mm out from the wound track, the "middle" core was 4.0 to 5.5mm from the edge of the wound track while the "outer" core ranged from 5.5 to 7.0mm from the track. The core samples along with the reference blood samples were then recounted to determine regional cerebral blood flow (rCBF) directly about the wound track. By this technique we measured rCBF in the brain as well as at increasing distances radially around the wound track.

Blood flows were determined in the following brain regions:

Upper Frontal Pole	Right/Left	Striatum R/L
Lower Frontal Pole	R/L	Thalamus R/L
Upper Frontal	R/L	Hypothalamus R/L
Lower Frontal-Temporal	R/L	Cerebellum R/L
Parietal	R/L	Mesencephalon R/L
Temporal	R/L	Tectum R/L
Upper Occipital Pole	R/L	Pons
Lower Occipital ole	R/L	Medulla
Hippocampus	R/L	Inner core
		Middle core
		Outer core

All tissue samples were counted on a Tracor gamma counter. Counts were processed on an IBM 9000 computer programmed to separate the 5 microsphere energies and to calculate CBFs provided by each microsphere. Flow was determined by the formula:

$$\text{Flow} = \frac{\text{Brain Counts}}{\text{Brain Weight}} \times \frac{\text{Reference Syringe Withdrawal Rate}}{\text{Reference Blood Counts}}$$

Preliminary experiments indicated that with the injected doses 250mg of brain would contain the requisite 400 microspheres.

CBF data was then correlated with simultaneously determined mean arterial blood pressures (MAPs), intracranial pressure (ICP), and cerebral perfusion pressures (CPPs); (CPP= MAP-ICP). Cerebrovascular resistance (CVR) was calculated as CPP/Flow. All data were analyzed for significance by ANOVA and Tukey's test. We evaluated rCBFs in four groups of animals: controls (N=5) and those wounded at 0.9 Joules (N=8), 1.4 Joules (N=8) and 2.4 Joules (N=7).

Data are expressed in the following units:

CBF (cerebral blood flow) ml/100g/min
rCBF (regional cerebral blood flow) ml/100g/min
MABP or MAP (mean arterial blood pressure) torr (mmHg)
CPP (cerebral perfusion pressure torr (mmHg)
ICP (intracranial pressure) torr (mmHg)
CVR (cerebral vascular resistance; CPP/F) CVR units

Results

Mean blood flow for control animals is shown in figure 3. These data indicate no significant CBF changes over the time course of these experiments and demonstrate that cerebral blood flow in our model was in a steady state condition.

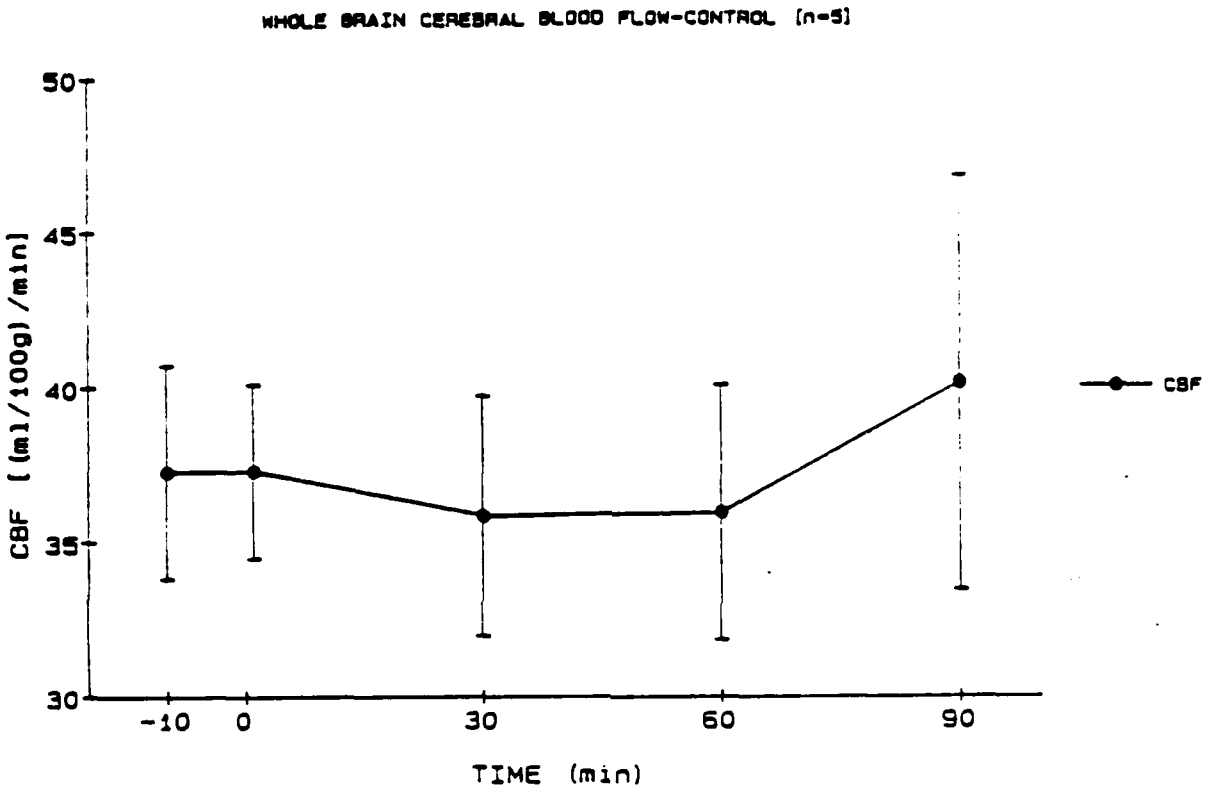


Figure 3: Mean whole brain blood flow for control animals. No significant blood flow change occurs during the experimental interval. Regional blood flows also showed no changes.

Wounded cats were grouped according to whether they appeared to have insignificant or large intracranial or intracerebral clots after wounding. Those with large clots had higher ICPs and lower CPPs which ranged between 37 and 52 Torr. These cats were designated as "complicated". All cats with such depressed CPPs showed a progressive and severe diminution in CBF over the time course of these experiments. This steady reduction in flow was discernable in both whole brain and regional flows. Values for the whole brain blood flows in these "complicated" animals with low CPPs are presented in table 1 and figure 4. Individual regional CBFs in this group are provided in Appendix 2.

TABLE 1

WHOLE BRAIN BLOOD FLOWS AND CEREBRAL VASCULAR RESISTANCE IN "COMPLICATED" CATS WOUNDED AT 0.9, 1.4, AND 2.4 J. [n=9]

	CONTROL	1 min	30 min	60 min	90 min
MABP MEAN (+/-SE)	114.4 (3.8)	162.6 (13.8)	122.1 (6.0)	110.1 (10.4)	128.0) (22.8)
CPP MEAN (+/-SE)	108.3 (4.0)	110.3 (8.7)	52.1* (9.7)	36.7* (9.7)	46.9* (12.3)
ICP MEAN (+/-SE)	6.1 (2.2)	52.3* (13.1)	70.0* (8.9)	73.4* (7.2)	82.1* (13.2)
WHOLE BRAIN CBF MEAN (+/-SE)	36.7 (4.4)	32.0 (4.6)	22.3*+ (3.6)	19.5*+ (4.0)	16.4*+ (4.6)
WHOLE BRAIN CVR MEAN (+/-SE)	3.5 (0.6)	4.1 (0.9)	3.9 (1.5)	4.4 (2.0)	- -

*-$p<0.05$ compared to control period (-10 min)

+-$p<0.05$ compared to corresponding contralateral area

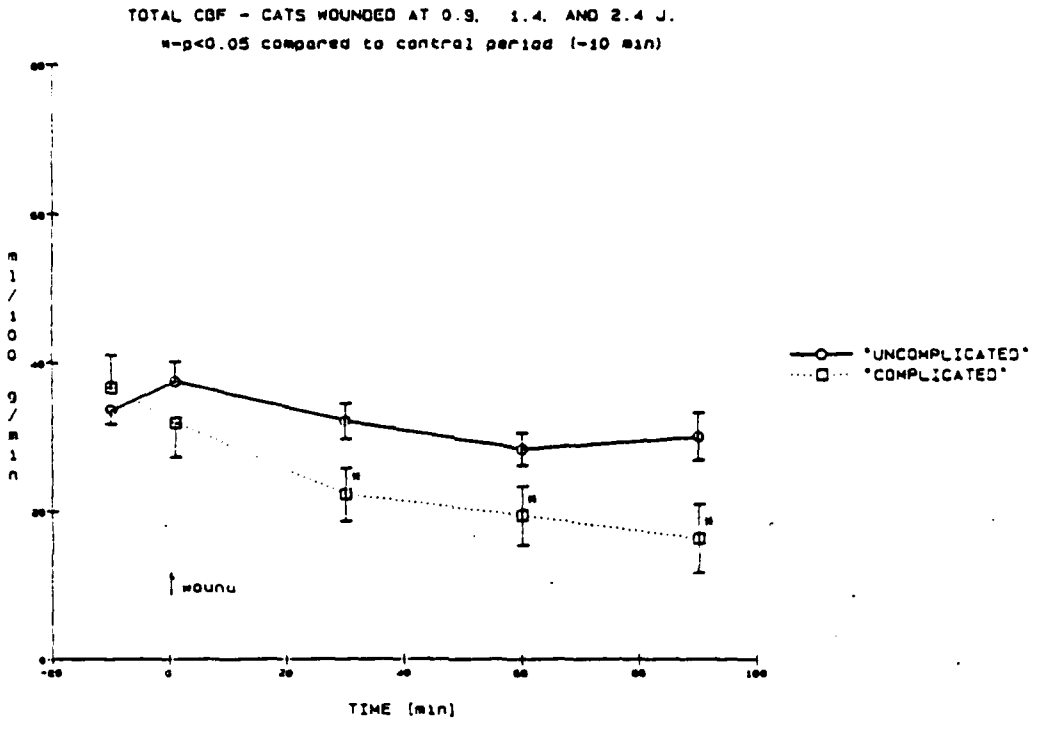


Figure 4: Whole brain blood flows for cats with large clots ("complicated" cats) and those with insignificant clots ("uncomplicated" cats). Large intracranial clots with high ICPs and low CPPs seriously reduced cerebral blood flow.

Cats with no significant clots, had lower ICPs and higher CPPs which approximated 75 Torr. These animals were considered "uncomplicated" and provided the most relevent information on post wounding blood flow. Whole brain blood flows in this group which had post wounding CPPs near 75 Torr showed no change in whole brain CBFs in the 90 minutes observed after wounding, table 2 and figure 4. Data for each individual brain region is presented in Appendix 1.

TABLE 2

WHOLE BRAIN BLOOD FLOW AND CEREBAL VASCULAR RESISTANCE IN "UNCOMPLICATED" CATS WOUNDED AT 0.9, 1.4, AND 2.4 J. [n=14]

	CONTROL	1 min	30 min	60 min	90 min
MABP MEAN	112.4	150.9*	116.1	112.1	116.2
(+/-SE)	(3.7)	(9.4)	(2.9)	(6.2)	(5.4)
CPP MEAN	106.9	110.7	73.8*	73.6*	76.0*
(+/-SE)	(3.6)	(8.4)	(6.2)	(8.7)	(8.1)
ICP MEAN	5.4	40.1*	41.5*	38.5*	40.1*
(+/-SE)	(0.7)	(6.8)	(5.9)	(4.5)	(5.0)
WHOLE BRAIN CBF MEAN	33.6	37.5	32.1	28.4	30.1
(+/-SE)	(1.9)	(2.7)	(2.4)	(2.2)	(3.2)
WHOLE BRAIN CVR MEAN	3.2	3.1	2.4	2.5	2.8
(+/-SE)	(0.1)	(0.3)	(0.2)	(0.3)	(0.3)

*-P<0.05 compared to control period (-10 min)

These "uncomplicated" cats demonstrated significant regional CBF changes, however, both at one and 30 minutes after wounding. Increased one minute blood flows occurred in the right and left upper frontal poles, the left parietal area, the left upper occipital pole and right tectum, table 3 and figures 5-9.

TABLE 3

REGIONAL CBFs AND CVRs IN "UNCOMPLICATED" CATS (SHOWING TRANSIENTLY INCREASED CBF AT 1 min)

RIGHT UPPER FRONTAL POLE

	CONTROL	1min	30min	60min	90 min
CBF					
MEAN	32.9	48.3*	53.3*+	32.7	32.0
(+/-SE)	(2.0)	(4.2)	(6.3)	(2.9)	(3.2)
CVR					
MEAN	3.3	2.4*	1.6*+	2.2*	2.5
(+/-SE)	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)

LEFT UPPER FRONTAL POLE

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	39.4	63.2*	35.6	33.0	35.1
(+/-SE)	(2.7)	(10.9)	(3.2)	(3.1)	(4.2)
CVR					
MEAN	2.9	2.2	2.5	2.3	2.2
(+/-SE)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)

LEFT PARIETAL

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	35.5	47.9*+	30.4	28.5	30.6
(+/-SE)	(2.2)	(5.2)	(2.2)	(2.5)	(3.4)
CVR					
MEAN	3.1	2.6	2.5	2.4	2.5
(+/-SE)	(0.1)	(0.3)	(0.2)	(0.3)	(0.3)

LEFT UPPER OCCIPITAL POLE

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	45.9	65.5*+	37.8	37.5	35.8
(+/-SE)	(3.7)	(8.2)	(3.2)	(3.9)	(4.4)
CVR					
MEAN	2.5	2.0	2.1	1.9	2.1
(+/-SE)	(0.2)	(0.3)	(0.2)	(0.2)	(0.2)

TABLE 3 (cont'd)

RIGHT TECTUM

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	41.4	65.3*	47.4	36.2	38.2
(+/-SE)	(2.7)	(7.9)	(6.1)	(4.5)	(5.0)
CVR					
MEAN	2.7	2.0	1.8*	2.0	2.0
(+/-SE)	(0.1)	(0.3)	(0.2)	(0.3)	(0.3)

*-$p<0.05$ compared to control period (-10 min)

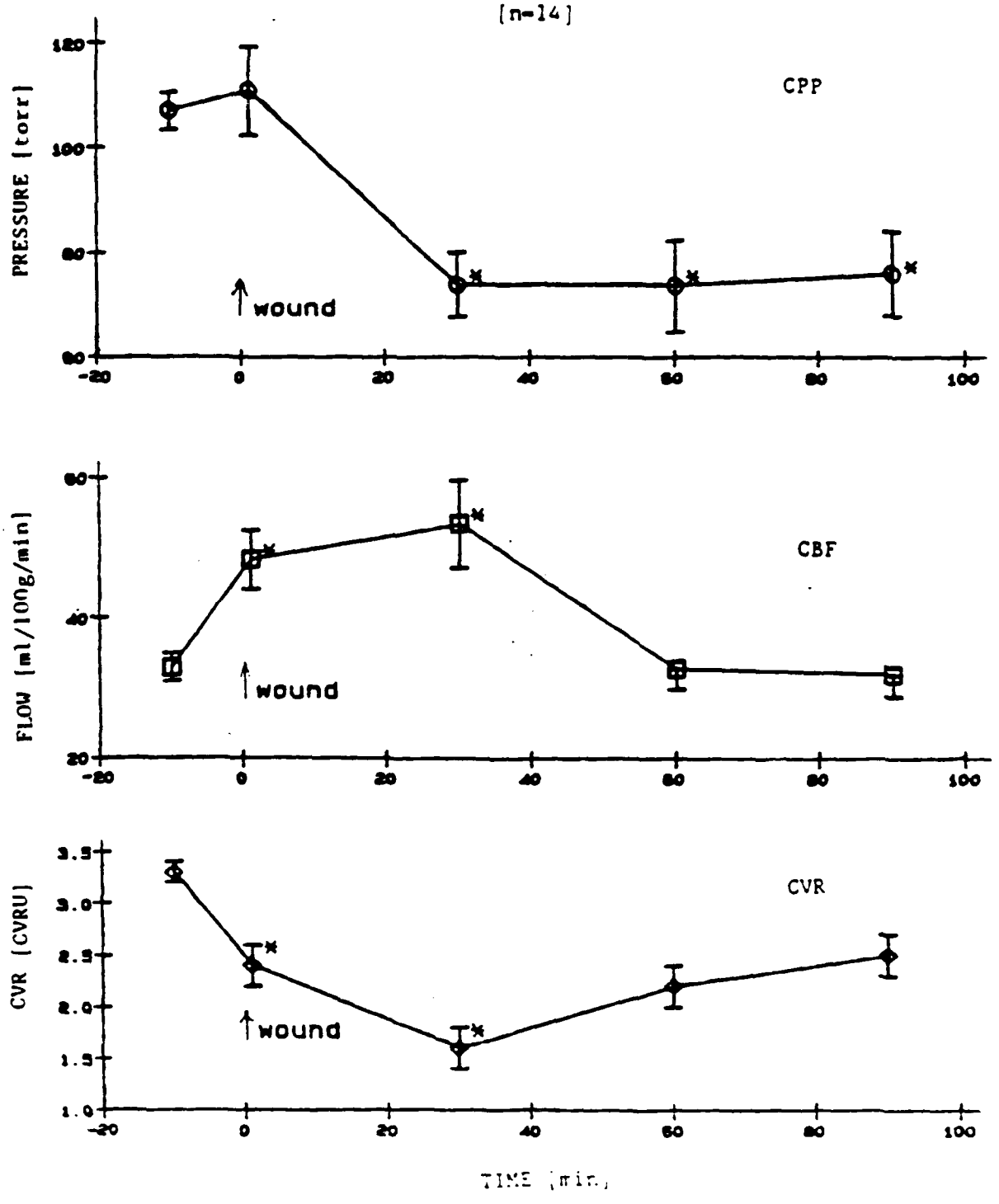
+-$p<0.05$ compared to corresponding contralateral area

These one minute CBF increases coincided with simultaneous elevation of the mean arterial pressure to 150 Torr immediately after wounding and, except for the right upper frontal pole which was directly damaged by the missile, were not associated with cerebral vascular resistance changes.

FIGURE 5

CPP AND RIGHT UPPER FRONTAL POLE CBF AND CVR IN 'UNCOMPLICATED' CATS

[n=14]

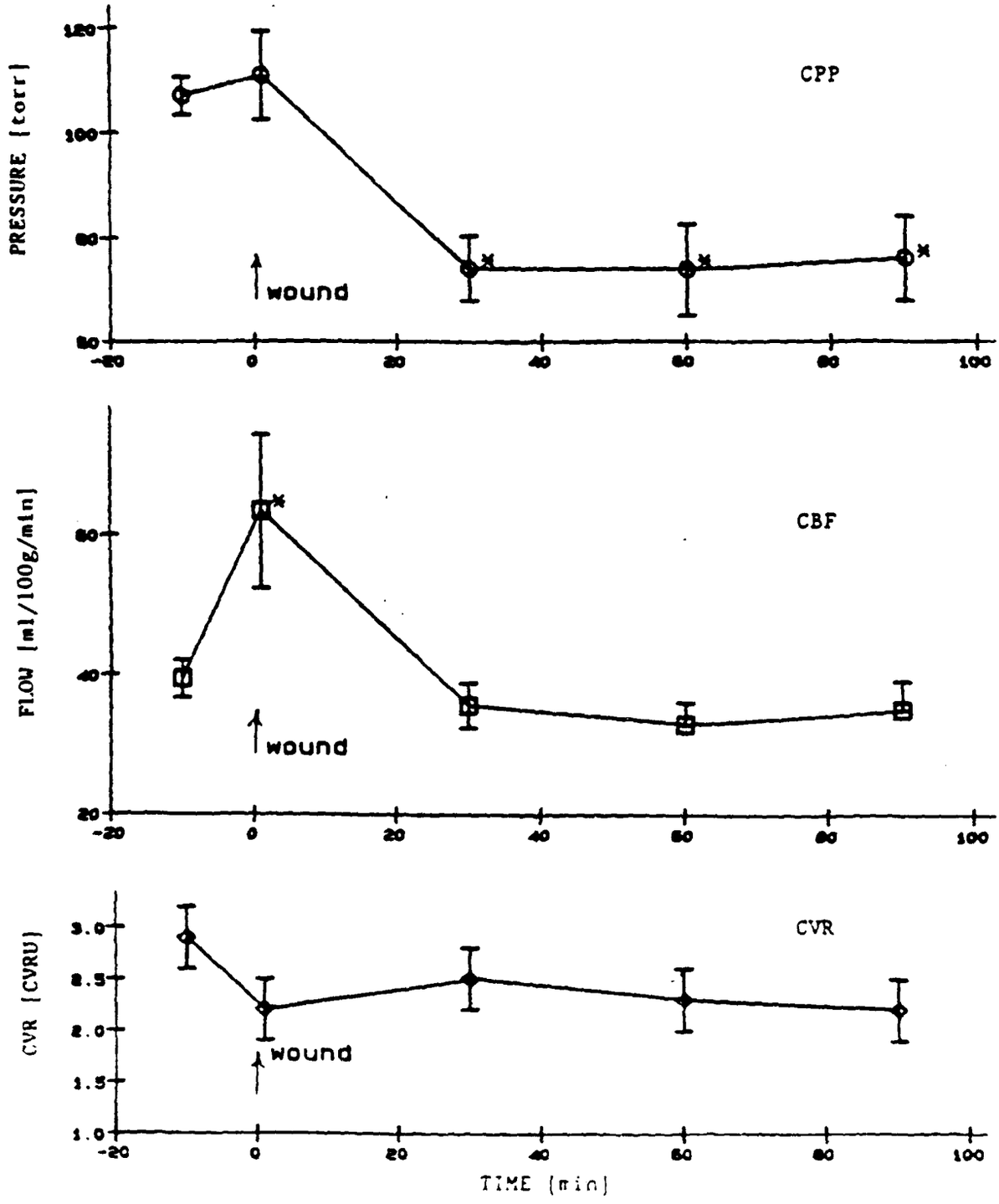


*-p<0.05 compared to control period (-10 min)

FIGURE 6

CPP AND LEFT UPPER FRONTAL POLE CBF AND CVR IN 'UNCOMPLICATED' CATS

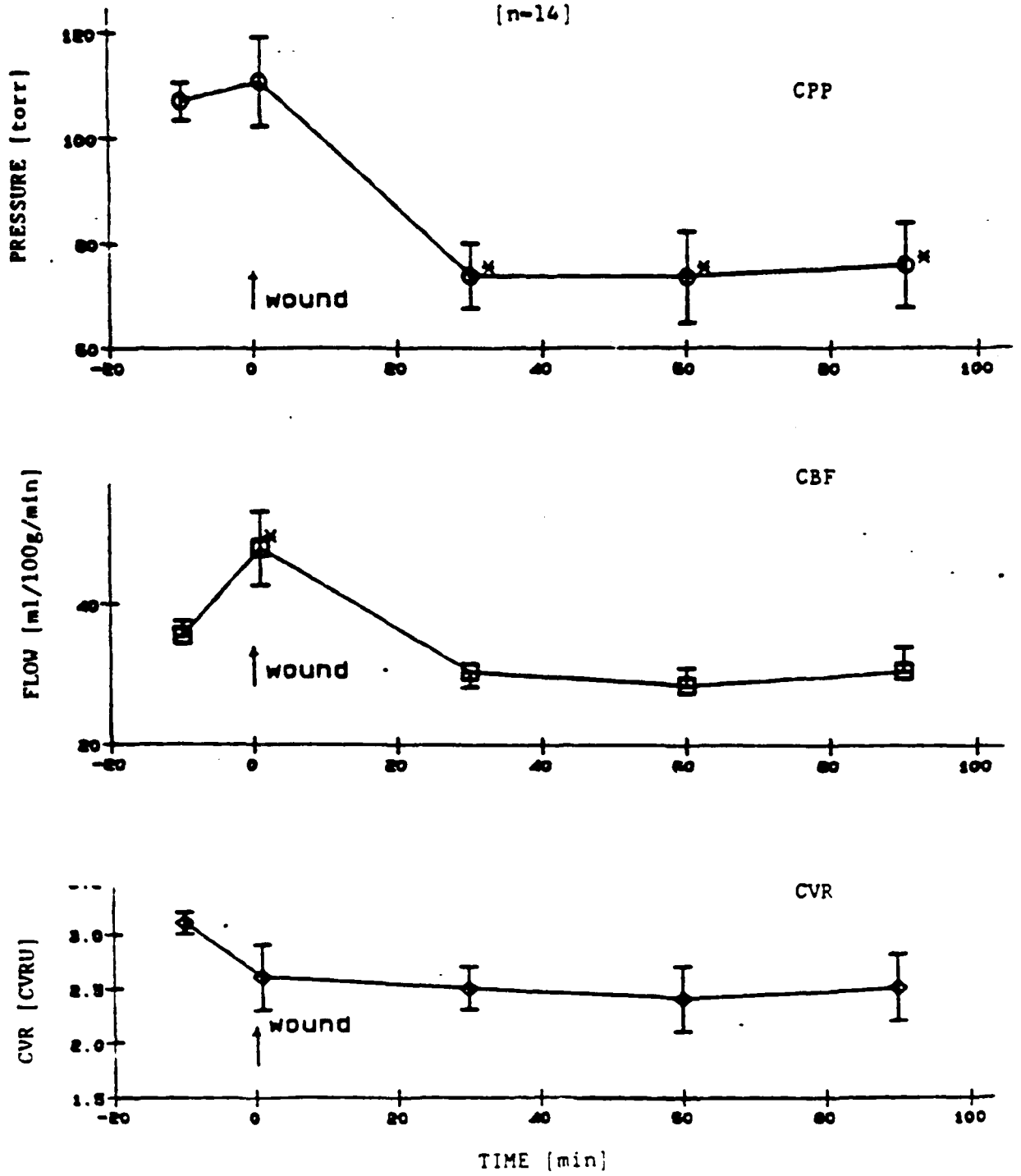
[n=14]



*-p<0.05 compared to control period (-10 min)

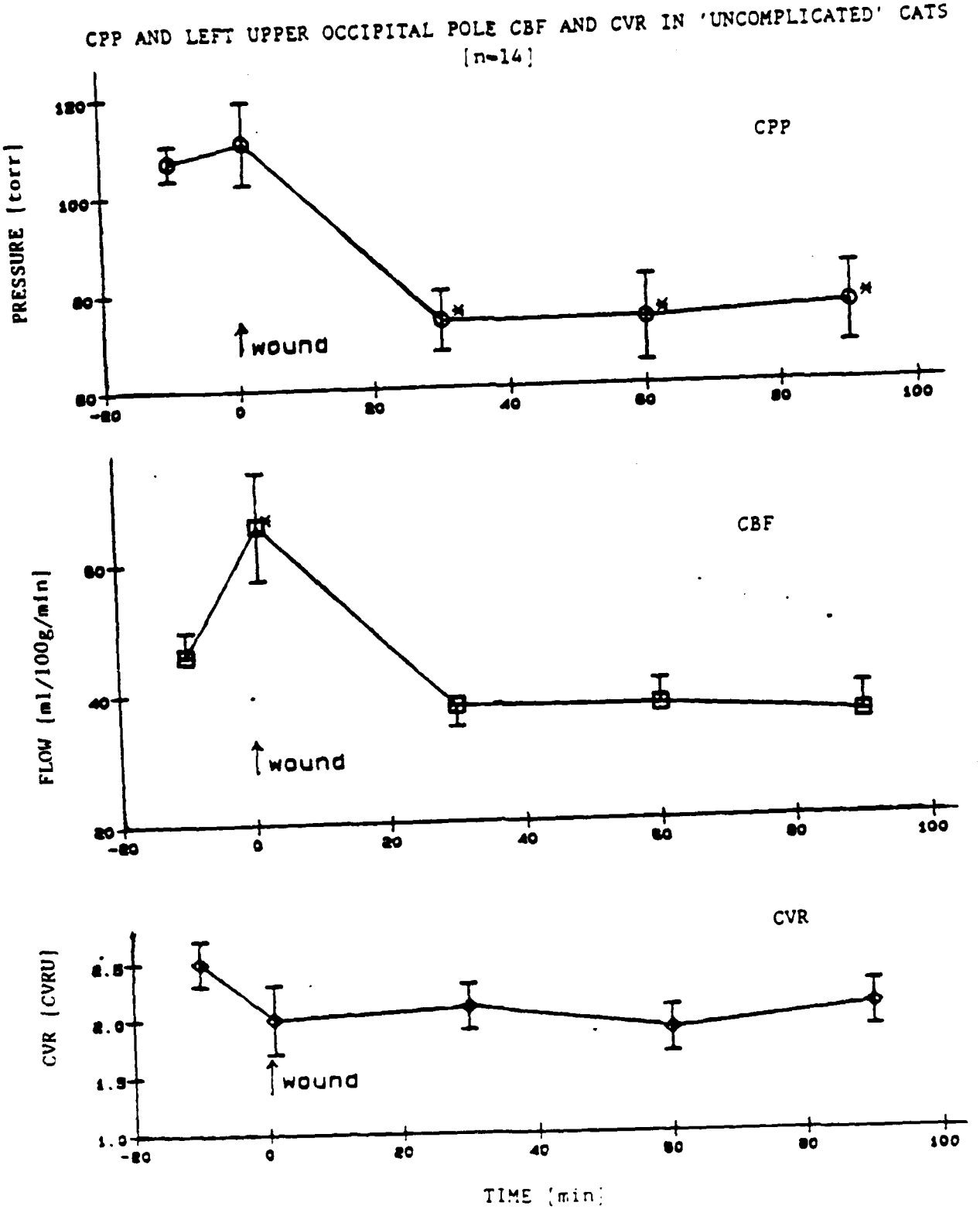
FIGURE 7

CPP AND LEFT PARIETAL CBF AND CVR IN 'UNCOMPLICATED' CATS



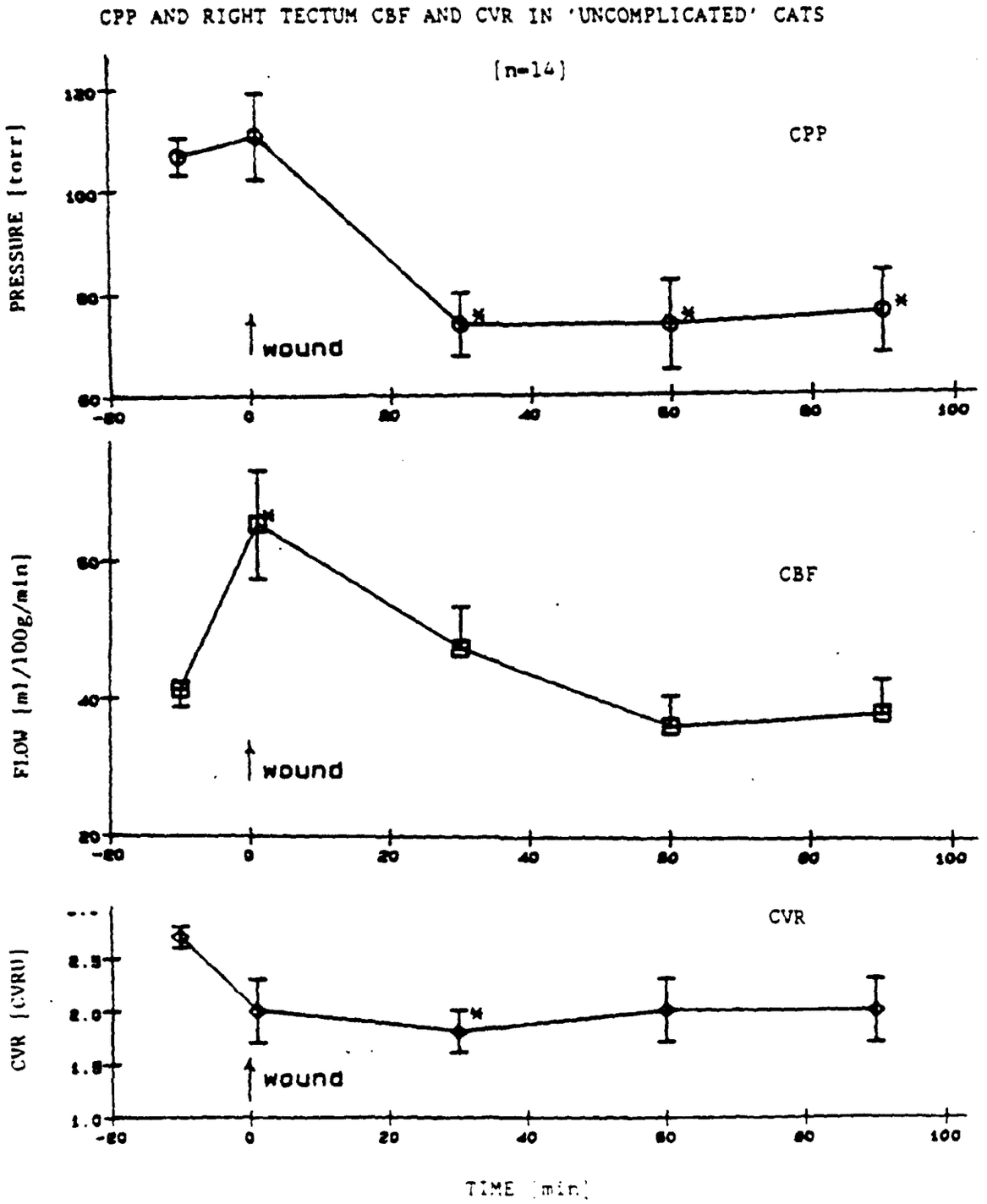
*-p<0.05 compared to control period (-10 min)

FIGURE 8



*-p<0.05 compared to control period (-10 min)

FIGURE 9



*-p<0.05 compared to control period (-10 min)

Several brain regions had significant reductions in cerebral vascular resistance and simultaneous CBF increases 30 minutes after wounding. These regions included the right upper frontal pole, the right upper frontal region and the right lower occipital pole, regions adjacent to the wound track itself, table 4, figures 10-15.

Realization that delayed CBF changes were occurring about the wound led to taking of brain specimens (cores) about the wound track. Both the inner and middle cores demonstrated highly significant decreases in CVRs and concomitant elevations in CBF 30 minutes after wounding, figures 13 and 14

TABLE 4

REGIONAL CBFs AND CVRs IN "UNCOMPLICATED" CATS
(SHOWING DECREASED CVR AND INCREASED CBF AT 30 min)

RIGHT UPPER FRONTAL POLE

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	32.9	48.3*	53.3*+	32.7	32.0
(+/-SE)	(2.0)	(4.2)	(6.3)	(2.9)	(3.2)
CVR					
MEAN	3.3	2.4*	1.6*+	2.2*	2.5
(+/-SE)	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)

RIGHT UPPER FRONTAL

	CONTROL	1 min	30min	60 min	90 min
CBF					
MEAN	26.0	31.1	34.5*+	25.3	25.4
(+/-SE)	(1.7)	(2.7)	(3.0)	(1.7)	(2.6)
CVR					
MEAN	4.2	4.0	2.3*	2.9*	2.9*
(+/-SE)	(0.2)	(0.5)	(0.2)	(0.4)	(0.3)

RIGHT LOWER OCCIPITAL POLE

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	31.9	29.1	45.7*+	26.0	25.5
(+/-SE)	(2.7)	(3.3)	(6.7)	(3.0)	(3.4)
CVR					
MEAN	3.6	4.2	2.2*	2.9	3.1
(+/-SE)	(0.2)	(0.5)	(0.3)	(0.3)	(0.3)

INNER CORE

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	26.7	32.3	61.0*	29.1	25.1
(+/-SE)	(1.7)	(3.2)	(8.5)	(3.0)	(2.9)
CVR					
MEAN	4.1	3.8	1.5*	2.5*	3.1
(+/-SE)	(0.2)	(0.4)	(0.2)	(0.3)	(0.3)

TABLE 4 (cont'd)

MIDDLE CORE

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	32.3	38.1	48.1*	31.5	31.0
(+/-SE)	(2.5)	(2.5)	(6.0)	(2.4)	(3.1)
CVR					
MEAN	3.5	3.0	1.1*	2.2*	2.4*
(+/-SE)	(0.2)	(0.3)	(0.3)	(0.3)	(0.2)

OUTER CORE

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	32.2	34.4	32.9	28.5	30.6
(+/-SE)	(2.5)	(1.9)	(2.9)	(2.0)	(3.2)
CVR					
MEAN	3.5	3.3	2.5	2.5	2.6
(+/-SE)	(0.2)	(0.3)	(0.3)	(0.4)	(0.2)

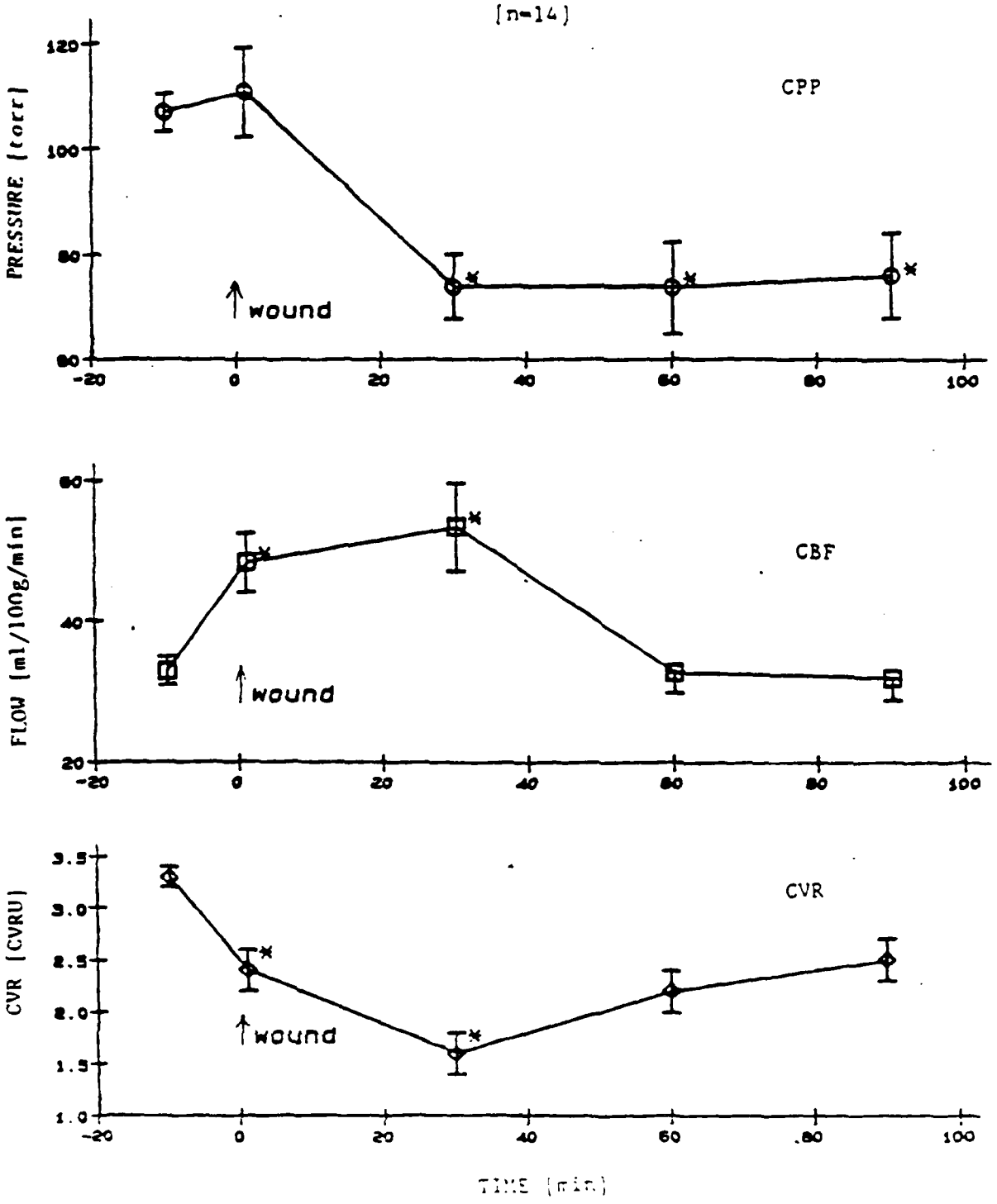
*-$p<0.05$ compared to control period (-10 min)

+-$p<0.05$ compared to corresponding contralateral area

FIGURE 10

CPP AND RIGHT UPPER FRONTAL POLE CBF AND CVR IN 'UNCOMPLICATED' CATS

(n=14)

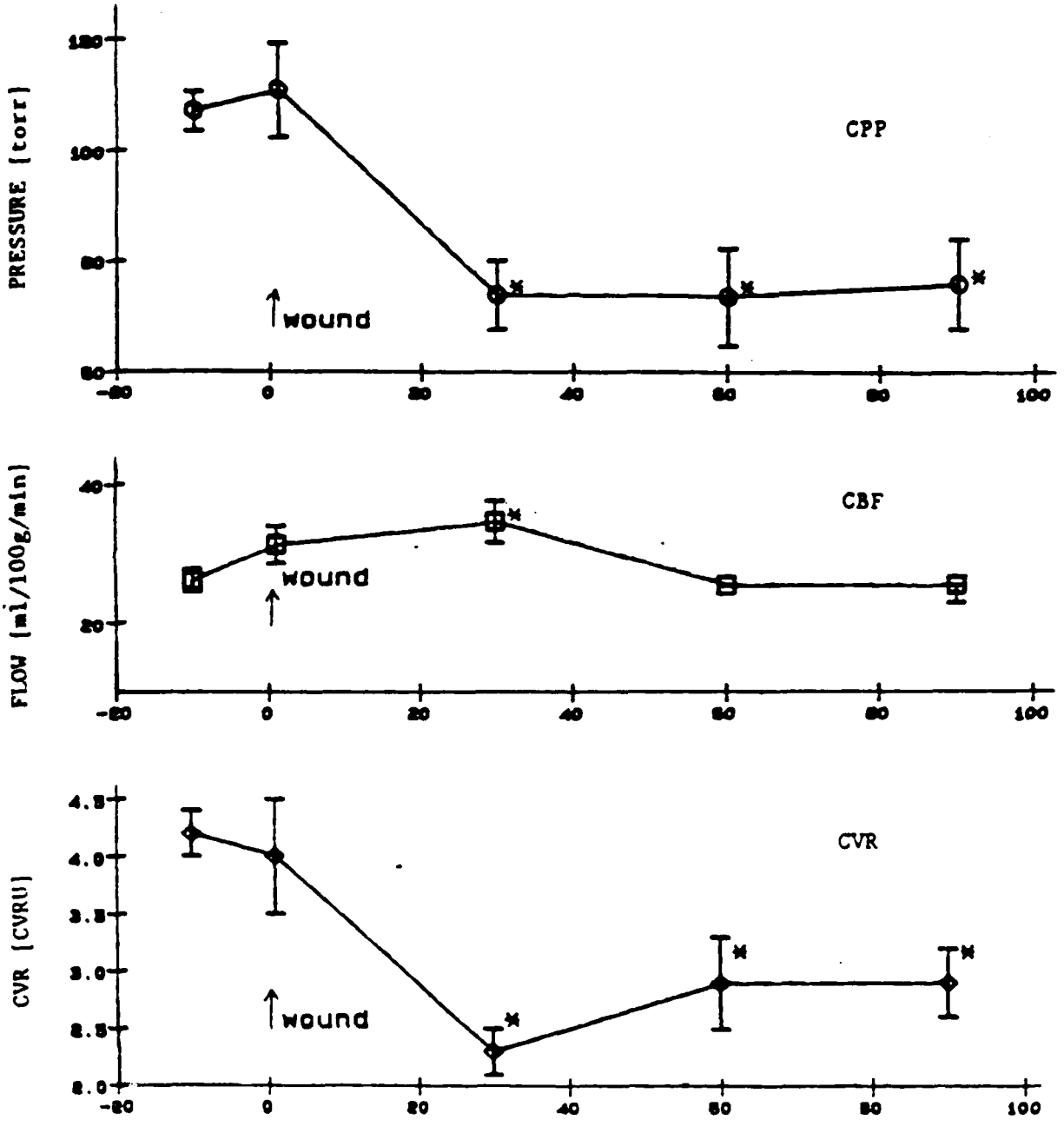


*-p<0.05 compared to control period (-10 min)

FIGURE 11

CPP AND RIGHT FRONTAL-TEMPORAL CBF AND CVR IN 'UNCOMPLICATED' CATS

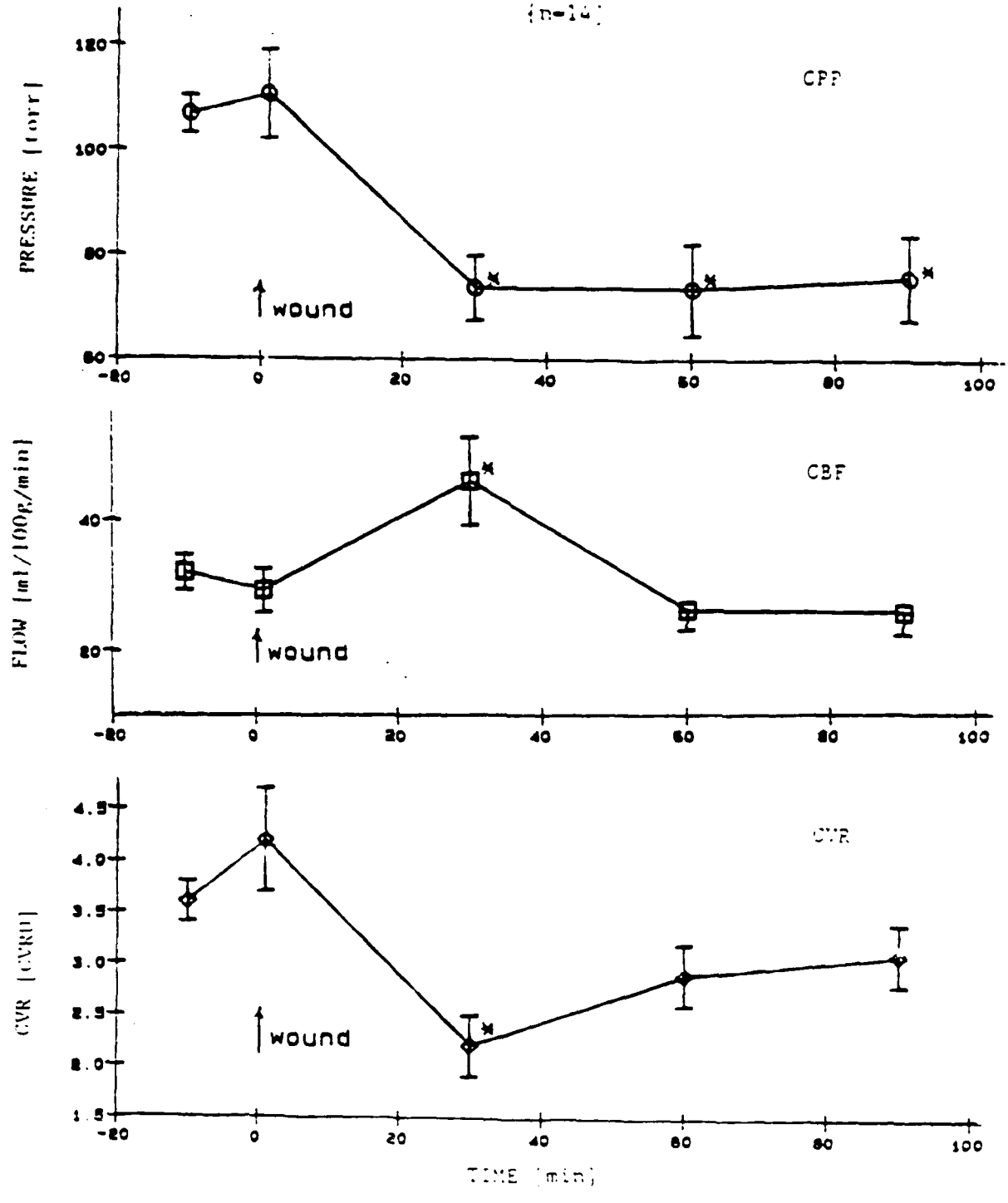
[n=14]



*-p<0.05 compared to control period (-10 min)

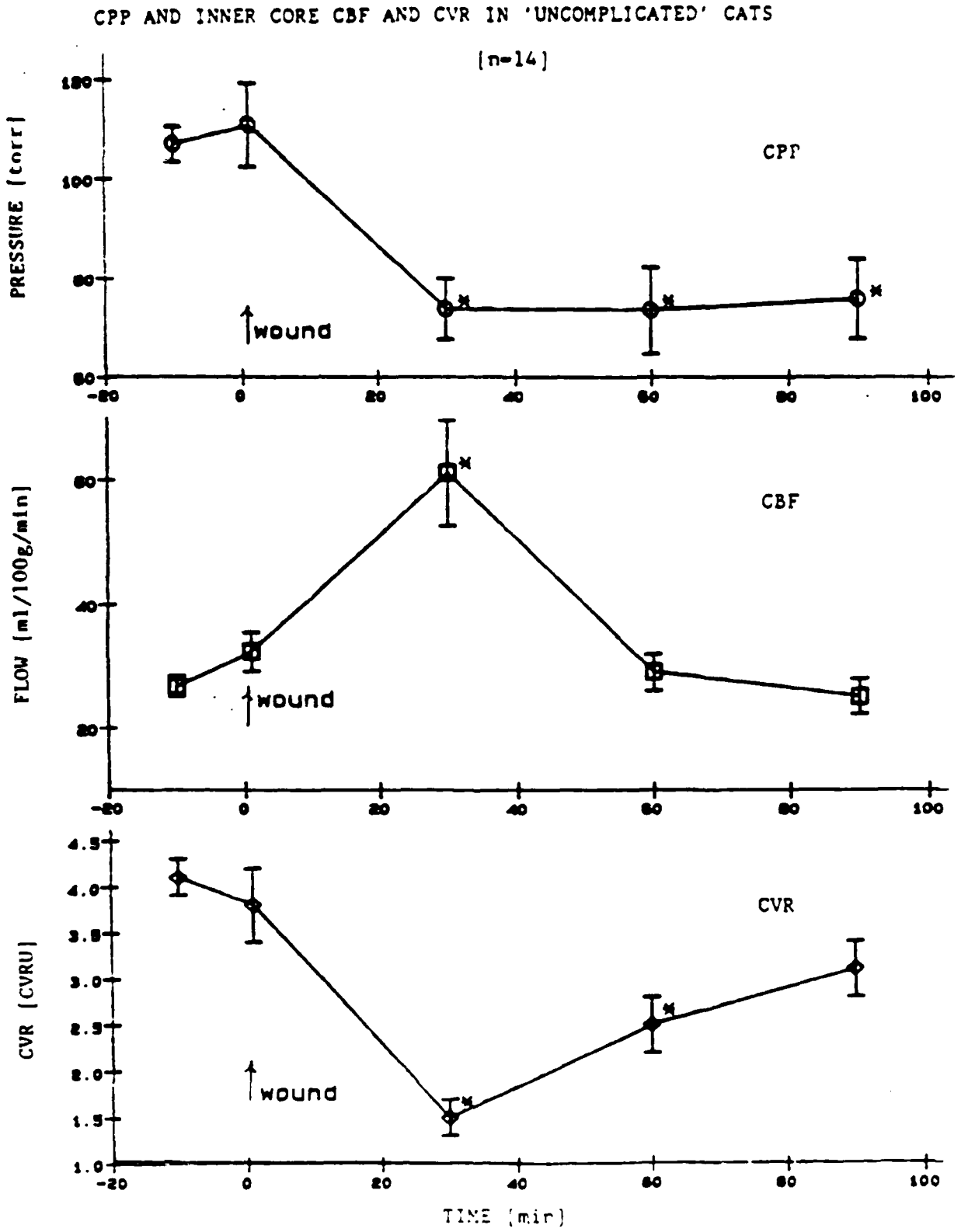
FIGURE 12

CPP AND RIGHT LOWER OCCIPITAL POLE CBF AND CVR IN 'UNCOMPLICATED' CATS (n=14)



*-p<0.05 compared to control period (-10 min)

FIGURE 13

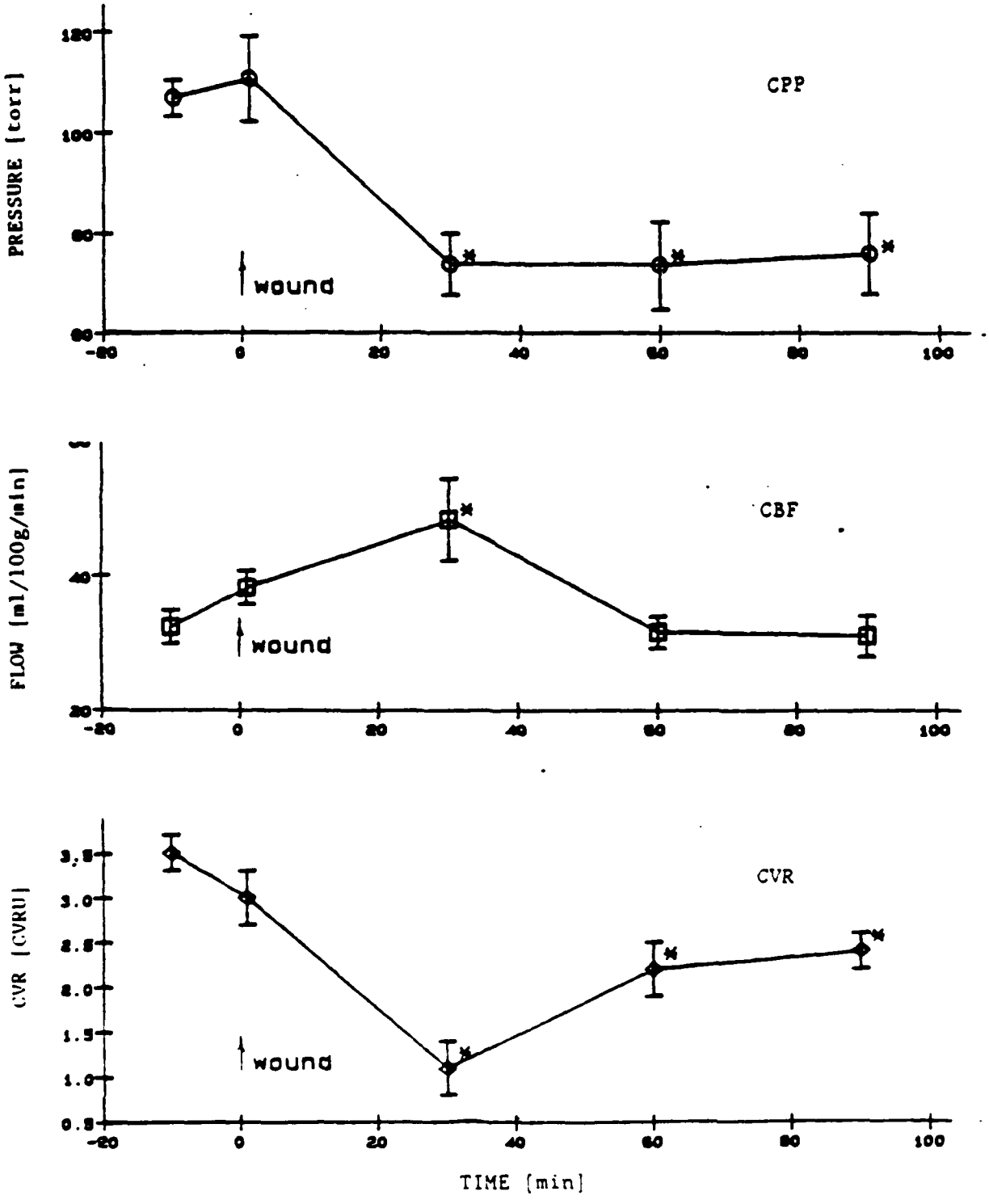


*-p<0.05 compared to control period (-10 min)

FIGURE 14

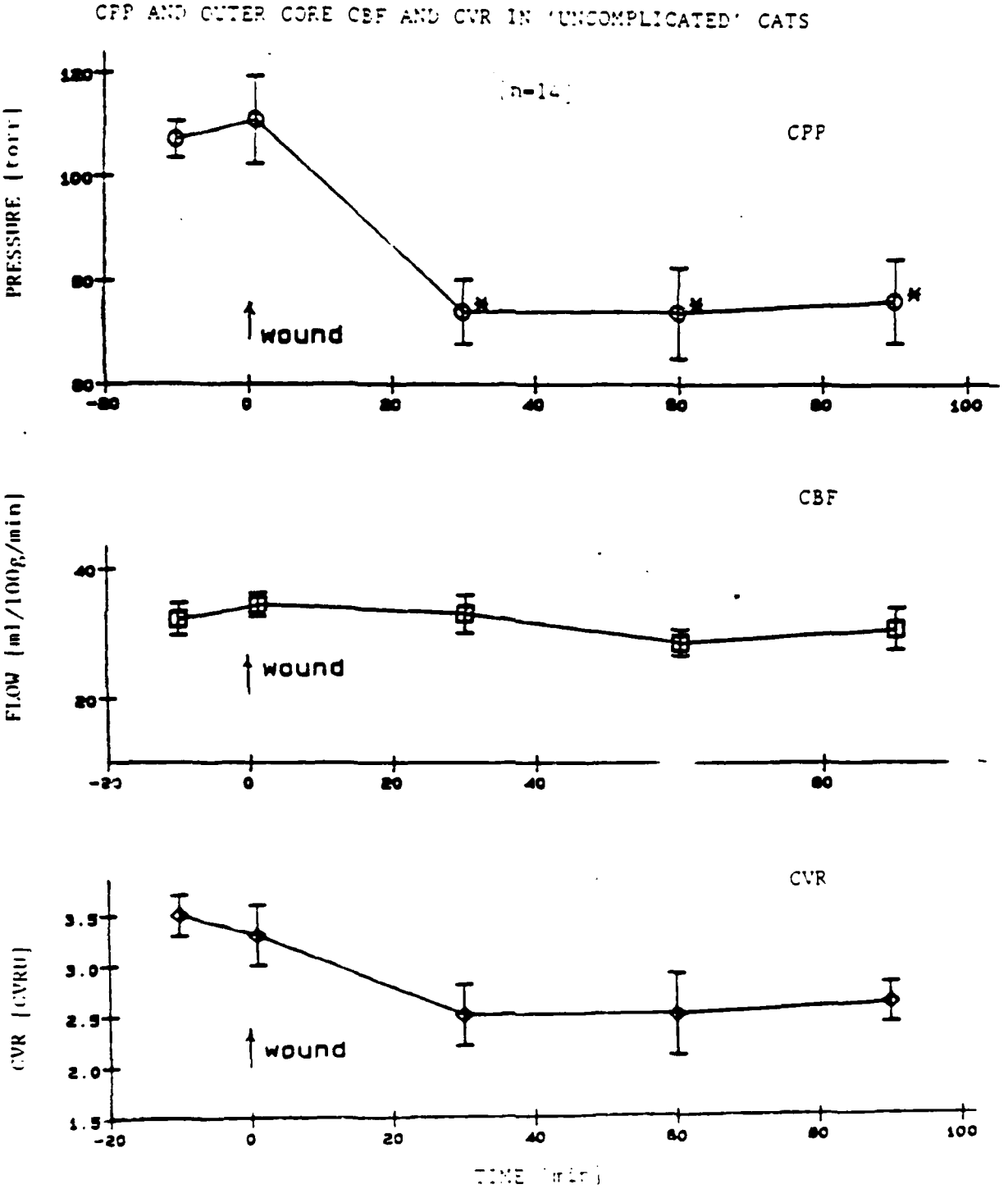
CPP AND MIDDLE CORE CBF AND CVR IN 'UNCOMPLICATED' CATS

[n=14]



*-p<0.05 compared to control period (-10 min)

FIGURE 15



*-p<0.05 compared to control period (-10 min)

Among the uncomplicated cats significant post wounding ischemia occurred in only brain two regions: the right lower frontal pole and the right caudate nucleus, table 5, figures 16 and 17. In each instance the ischemia which occurred 30 minutes following the wound was mild.

TABLE 5

REGIONAL CBFs AND CVRs IN "UNCOMPLICATED" CATS
(SHOWING MILD ISCHEMIA)

RIGHT LOWER FRONTAL POLE

	CONTROL	1 min	30 min	60 min	90min
CBF					
MEAN	28.1	28.8	22.5*	24.4	25.6
(+/-SE)	(1.8)	(2.2)	(1.7)	(1.7)	(2.9)
CVR					
MEAN	4.0	4.2	3.7	3.1	3.1
(+/-SE)	(0.2)	(0.5)	(0.6)	(0.5)	(0.5)

RIGHT CAUDATE

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	60.9	67.8	39.4*	46.2	49.5
(+/-SE)	(4.5)	(5.6)	(3.4)	(5.0)	(6.8)
CVR					
MEAN	1.8	1.7	1.9	1.7	2.0
(+/-SE)	(0.1)	(0.2)	(0.2)	(0.3)	(0.3)

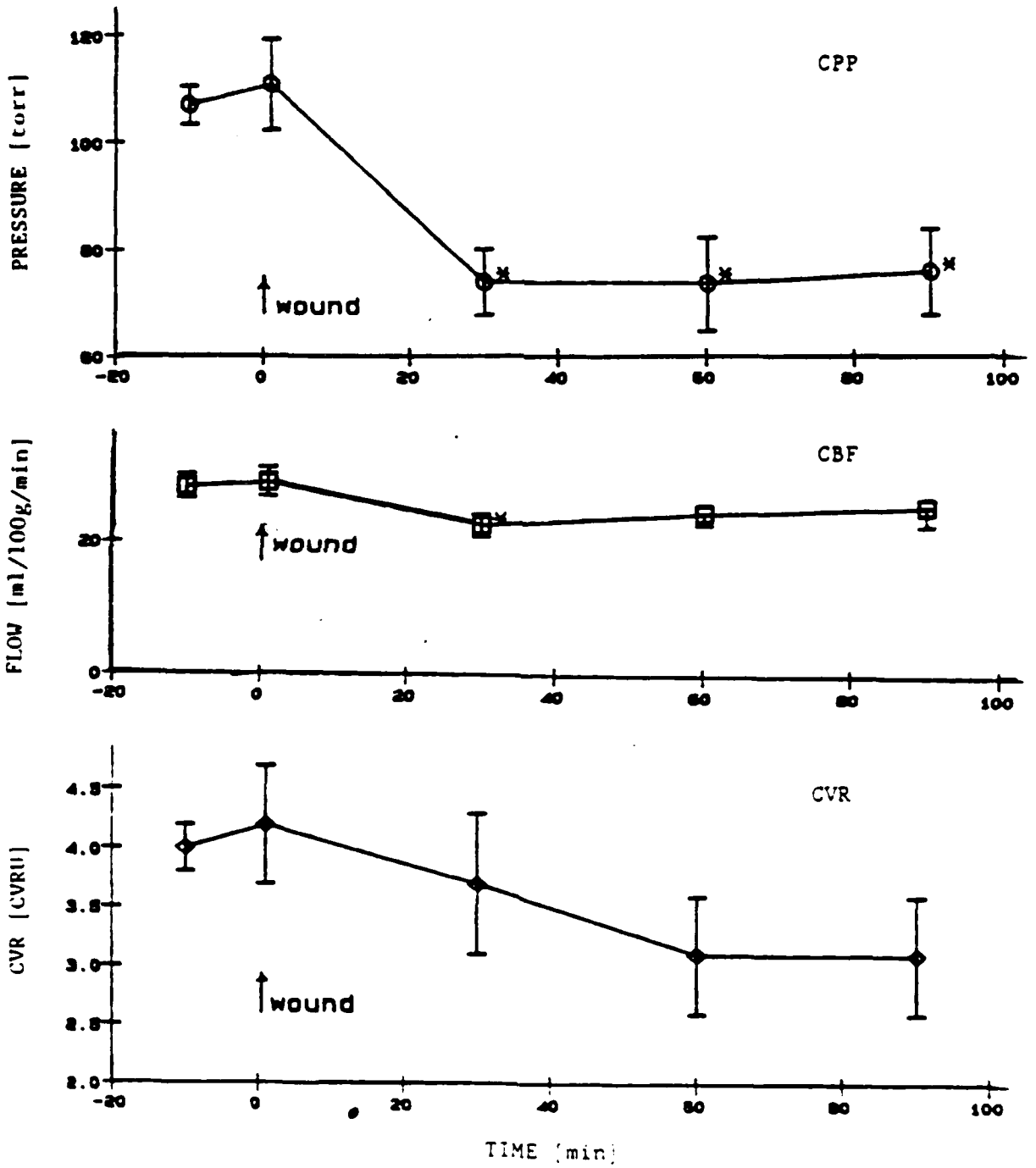
*-$p<0.05$ compared to control period (-10 min)

+-$p<0.05$ compared to corresponding contralateral area

FIGURE 16

CPP AND RIGHT LOWER FRONTAL POLE CBF AND CVR IN 'UNCOMPLICATED' CATS

[n=14]

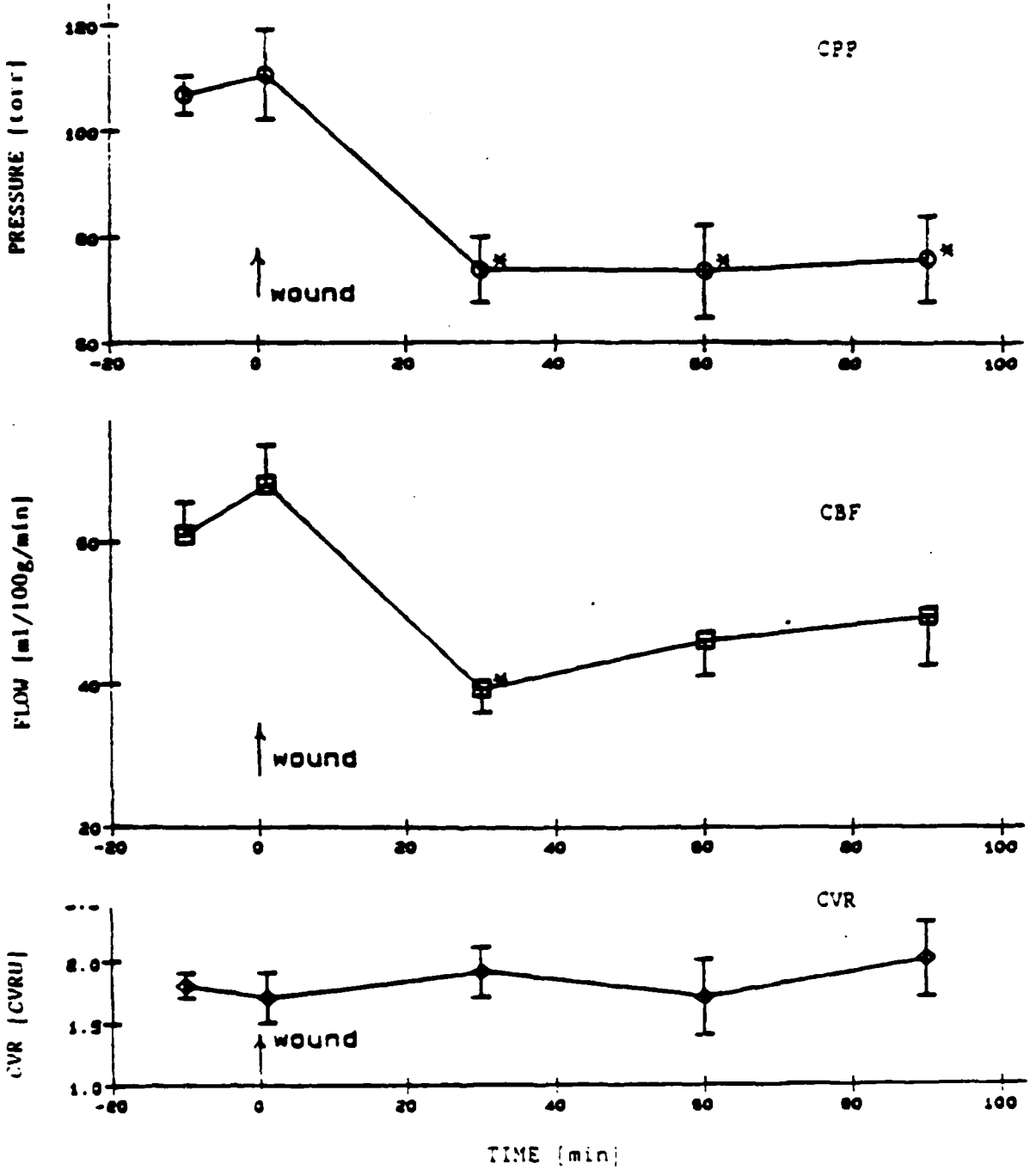


*-p<0.05 compared to control period (-10 min)

FIGURE 17

CPP AND RIGHT CAUDATE CBF AND CVR IN 'UNCOMPLICATED' CATS

(n=14)



*-p<0.05 compared to control period (-10 min)

In "uncomplicated" animals with no significant post-wounding clots, (thus having lower ICPs and higher CPPs), many brain regions, notably the brain stem structures, showed no blood flow alterations whatsoever after wounding, table 6. Because so many regions demonstrated no CBF alterations whole brain blood flow did not change appreciably after wounding in this "uncomplicated" group.

TABLE 6

REGIONAL CBFs AND CVRs IN "UNCOMPLICATED" CATS
(SHOWING NO CHANGE)

LEFT LOWER FRONTAL POLE

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	33.3 (2.4)	39.5+ (4.1)	30.3 (2.6)	27.9 (2.5)	30.2 (4.0)
CVR MEAN (+/-SE)	3.3 (0.2)	3.3 (0.4)	2.7 (0.3)	2.7 (0.4)	2.6 (0.4)

LEFT UPPER FRONTAL

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	30.9 (2.0)	39.5 (4.7)	27.0 (2.0)	25.4 (2.4)	26.7 (3.1)
CVR MEAN (+/-SE)	3.6 (0.2)	3.2 (0.4)	2.9 (0.3)	2.9 (0.4)	2.9 (0.4)

RIGHT LOWER FRONTAL-TEMPORAL

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	20.0 (1.2)	17.8 (1.2)	17.0 (1.2)	16.8 (1.5)	19.4 (2.1)
CVR MEAN (+/-SE)	5.5 (0.3)	6.9 (0.8)	4.7 (0.7)	4.6 (0.8)	4.1 (0.5)

LEFT LOWER FRONTAL-TEMPORAL

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	17.4 (1.1)	19.5 (1.4)	17.3 (1.6)	15.9 (1.5)	17.5 (2.2)
CVR MEAN (+/-SE)	6.6 (0.6)	6.4 (0.9)	5.2 (1.2)	5.1 (1.1)	4.7 (0.8)

TABLE 6 (cont'd)

RIGHT PARIETAL

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	32.0 (1.5)	32.3 (3.5)	32.2 (3.6)	27.6 (2.0)	28.4 (2.9)
CVR MEAN (+/-SE)	3.4 (0.1)	3.9 (0.5)	2.7 (0.4)	2.6 (0.3)	2.6 (0.3)

RIGHT TEMPORAL

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	29.9 (2.0)	33.8 (2.6)	32.2 (3.5)	25.5 (2.1)	26.0 (2.8)
CVR MEAN (+/-SE)	3.7 (0.2)	3.6 (0.4)	2.5* (0.2)	2.8 (0.3)	3.0 (0.4)

LEFT TEMPORAL

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	31.1 (2.2)	32.1 (2.2)	26.3 (1.9)	25.5 (2.1)	27.3 (3.1)
CVR MEAN (+/-SE)	3.6 (0.2)	3.7 (0.4)	3.0 (0.4)	2.9 (0.4)	2.7 (0.3)

RIGHT UPPER OCCIPITAL POLE

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	42.8 (3.1)	40.6 (3.1)	38.0 (3.6)	33.6 (2.5)	35.7 (3.9)
CVR MEAN (+/-SE)	2.6 (0.1)	2.9 (0.3)	2.1 (0.2)	2.1 (0.2)	2.1 (0.2)

* $p<0.05$ compared to control period

TABLE 6 (cont'd)

LEFT LOWER OCCIPITAL POLE

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	37.9 (2.4)	47.0+ (5.9)	30.7 (2.6)	31.8 (4.1)	30.4 (4.0)
CVR MEAN (+/-SE)	2.9 (0.1)	2.7 (0.3)	2.6 (0.3)	2.4 (0.3)	2.6 (0.3)

RIGHT HIPPOCAMPUS

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	26.0 (1.6)	34.5 (3.5)	26.1 (4.5)	23.6 (2.8)	22.2 (2.7)
CVR MEAN (+/-SE)	4.3 (0.2)	3.7 (0.5)	3.4 (0.4)	3.1 (0.4)	3.4 (0.4)

LEFT HIPPOCAMPUS

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	24.4 (2.1)	24.7 (1.8)	23.6 (3.0)	22.1 (2.8)	22.6 (3.3)
CVR MEAN (+/-SE)	4.8 (0.4)	4.9 (0.6)	3.9 (0.5)	3.7 (0.7)	3.8 (0.7)

LEFT CAUDATE

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	58.6 (4.3)	67.2 (6.7)	45.8 (3.7)	48.1 (5.4)	51.6 (6.4)
CVR MEAN (+/-SE)	1.9 (0.1)	1.8 (0.2)	1.7 (0.2)	1.5 (0.2)	1.8 (0.2)

TABLE 6 (cont'd)

RIGHT THALAMUS

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	39.8	47.6	35.0	32.9	34.7
(+/-SE)	(1.9)	(4.6)	(2.8)	(3.5)	(4.0)
CVR					
MEAN	2.7	2.6	2.3	2.2	2.2
(+/-SE)	(0.1)	(0.3)	(0.3)	(0.3)	(0.2)

LEFT THALAMUS

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	39.5	38.1	34.0	31.1	33.7
(+/-SE)	(2.4)	(2.5)	(4.4)	(3.7)	(4.8)
CVR					
MEAN	2.8	3.0	2.6	2.4	2.4
(+/-SE)	(0.1)	(0.3)	(0.3)	(0.3)	(0.3)

RIGHT HYPOTHALAMUS

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	21.1	20.2	21.4	17.5	20.5
(+/-SE)	(1.8)	(2.5)	(3.3)	(2.2)	(3.3)
CVR					
MEAN	5.5	6.8	4.7	4.6	4.3
(+/-SE)	(0.4)	(0.9)	(0.9)	(0.8)	(0.8)

LEFT HYPOTHALAMUS

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	18.0	19.1	19.0	17.1	19.2
(+/-SE)	(1.9)	(2.2)	(3.1)	(3.0)	(2.6)
CVR					
MEAN	6.5	7.6	5.7	5.0	4.1
(+/-SE)	(0.5)	(1.5)	(1.2)	(0.8)	(0.5)

TABLE 6 (cont'd)

LEFT LOWER OCCIPITAL POLE

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	37.9	47.0+	30.7	31.8	30.4
(+/-SE)	(2.4)	(5.9)	(2.6)	(4.1)	(4.0)
CVR					
MEAN	2.9	2.7	2.6	2.4	2.6
(+/-SE)	(0.1)	(0.3)	(0.3)	(0.3)	(0.3)

RIGHT HIPPOCAMPUS

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	26.0	34.5	26.1	23.6	22.2
(+/-SE)	(1.6)	(3.5)	(4.5)	(2.8)	(2.7)
CVR					
MEAN	4.3	3.7	3.4	3.1	3.4
(+/-SE)	(0.2)	(0.5)	(0.4)	(0.4)	(0.4)

LEFT HIPPOCAMPUS

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	24.4	24.7	23.6	22.1	22.6
(+/-SE)	(2.1)	(1.8)	(3.0)	(2.8)	(3.3)
CVR					
MEAN	4.8	4.9	3.9	3.7	3.8
(+/-SE)	(0.4)	(0.6)	(0.5)	(0.7)	(0.7)

LEFT CAUDATE

	CONTROL	1 min	30 min	60 min	90 min
CBF					
MEAN	58.6	67.2	45.8	48.1	51.6
(+/-SE)	(4.3)	(6.7)	(3.7)	(5.4)	(6.4)
CVR					
MEAN	1.9	1.8	1.7	1.5	1.8
(+/-SE)	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)

TABLE 6 (cont'd)

RIGHT THALAMUS

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	39.8 (1.9)	47.6 (4.6)	35.0 (2.8)	32.9 (3.5)	34.7 (4.0)
CVR MEAN (+/-SE)	2.7 (0.1)	2.6 (0.3)	2.3 (0.3)	2.2 (0.3)	2.2 (0.2)

LEFT THALAMUS

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	39.5 (2.4)	38.1 (2.5)	34.0 (4.4)	31.1 (3.7)	33.7 (4.8)
CVR MEAN (+/-SE)	2.8 (0.1)	3.0 (0.3)	2.6 (0.3)	2.4 (0.3)	2.4 (0.3)

RIGHT HYPOTHALAMUS

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	21.1 (1.8)	20.2 (2.5)	21.4 (3.3)	17.5 (2.2)	20.5 (3.3)
CVR MEAN (+/-SE)	5.5 (0.4)	6.8 (0.9)	4.7 (0.9)	4.6 (0.8)	4.3 (0.8)

LEFT HYPOTHALAMUS

	CONTROL	1 min	30 min	60 min	90 min
CBF MEAN (+/-SE)	18.0 (1.9)	19.1 (2.2)	19.0 (3.1)	17.1 (3.0)	19.2 (2.6)
CVR MEAN (+/-SE)	6.5 (0.5)	7.6 (1.5)	5.7 (1.2)	5.0 (0.8)	4.1 (0.5)

Arterial blood gases were monitored closely throughout the experiment. Respirator adjustments and bicarbonate administration maintained arterial PCO_2, PO_2 and pH constant throughout, table 7.

Table 7

pH, $PaCO_2$, and PaO_2

	control	1 minute	30 minutes	60 minutes	90 minutes
pH	7.39±.01	7.39±.01	7.38±.01	7.41±.01	7.38+.01
PaCO2	32.4±1.8	30.5±0.6	30.1±1.1	30.0±1.1	30.4+1.4
PaO2	103.9±10.8	107.9±13.2	106.9±12.0	106.5±11.1	105.9±8.8

Arteriovenous shunting was assessed in 4 animals by sampling blood from the posterior sagittal sinus each time a CBF was determined. Of 2 "uncomplicated" animals (one each at 1.4 and 2.4 Joules) all A-V shunting was less than 3% except at 60 minutes for the cat wounded at 2.4 Joules where a 10% shunt was demonstrated. One "complicated" cat wounded at 1.4 Joules had A-V shunting less than 2% for all injections but another "complicated" cat with almost no CBF demonstrated up to a 39% shunt. By and large this report concerns itself with rCBF alterations in "uncomplicated" cats where shunting was negligable especially at the time points where we have detected changes in rCBFs.

Discussion

Post wounding, ICPs, CPPs and brain blood flows exhibited two distinct patterns. Fourteen cats (5 wounded at 0.9 and 1.4J and 4 wounded at 2.4J) had post wounding ICPs of 40 Torr and were able to maintain their CPPs in the range of 75 Torr. Post wounding whole brain blood flow in these animals was not significantly different from pre-wound flow, table 2, figure 4.

Nine animals (3 at each wound energy) developed excessively high post wounding ICPs in the range of 75 Torr which lead to CPPs in the range of 37-52 Torr. The exact cause of the high ICPs cannot be stated with precision. While the most obvious cause appeared to have been excessive intracranial bleeding, increased intravascular volume, increased cerebrospinal fluid (CSF) formation or decreased CSF formation may also have contributed to the excessively high ICP in these cats. Whatever

the cause, those cats exhibiting high ICPs and reduced CPPs, developed very depressed whole and regional brain blood flows which decreased into the range where major cellular abnormalities and cell death would occur. We feel that these animals (almost 40% of the total) suffered fatal brain wounds by virtue of their high post wounding ICPs, low CPPs and resultant severe generalized brain ischemia. Of interest in this group, however, is that blood flow to brain stem structures was better preserved than to the cerebral hemispheres.

This bimodal pattern of post wounding ICPs, CPPs and hemispheral CBFs was also observed by Crockard who wounded monkeys at 1.3 Joules. His experimental monkeys which lived more than 6 hours had post wounding CPPs of about 50 Torr and blood flows which ranged from 20 to 28 ml/100g/min, (reduced from 42ml/100g/min before wounding). Brain wounded monkeys which lived less than 6 hours had CPPs about 25 Torr and post wounding CBFs of 10 to 20ml/100g/min. Djordevic observed that dogs wounded at 1.9 Joules had about a 50% reduction in CBF but this decreased flow tended to remain stable. Animals wounded at about 40 and 120 Joules showed a relentless reduction in hemispheral CBF often to nonviable levels.

Our regional CBF data provide for the first time more specific information on brain blood flow changes associated with a non-fatal wound. We observed 3 different patterns of regional blood flow changes following such a wound:

1) In brain areas directly injured by the missile or where contra coup effects might be expected a transient increase in CBF occurred one minute after wounding. Since this CBF rise was generally unassociated with changes in vascular resistance and occurred simultaneously with mean arterial pressure elevations consequent to wounding, we infer that direct missile trauma disrupted local brain blood flow autoregulatory mechanisms. This effect was observed in the right frontal pole where the missile entered the brain and the right occipital pole where the missile came to rest. One minute post wounding CBF increases were seen also in the left frontal and occipital poles as well as the tectum. We infer that missile energy, disruptive to blood flow autoregulatory mechanisms, was preferentially transfered to these areas at a distance from the actual missile track. The transient CBF rise in the left parietal area occurred adjacent to the subdural pressure transducer and could represent either a contre coup effect or an artifact caused by the transducer itself. This early effect on CBF is similar to early CBF rises observed in the percussion model of brain injury.(5) In the percussion model the CBF rise is global whereas with missile wounding this effect is much more restricted being found primarily in the coup and contracoup areas.

2) A later (also transient) rise in CBF occurred 30 minutes after wounding in hemispheral areas directly injured by the missile. This late increase in CBF was best seen in the core specimens taken directly about the wound track and in all instances was directly associated with decreased cerebrovascular

resistance. We infer, therefore, that substances directly associated with brain damage per se dilated precapillary arterioles (at least transiently after wounding), reduced vascular resistance, and allowed a local CBF increase. This is the first time such an effect has been observed following a brain wound. The nature of the vasodilatory substance is unknown but lactic acid, prostacyclin and adenosine are powerful vasodilators and should be considered. This later rise in CBF is totally absent in the percussion injury model and evidently occurs consequent to the direct tissue damage.

3) Two brain areas, the right lower frontal pole and right caudate nucleus, became mildly ischemic relative to their control blood flows shortly after wounding. Though singificant, these CBF reductions would not appear to have been severe enough to impair brain function. The reduction in right lower frontal pole CBF may have resulted from the decreased CVR in the adjacent right upper frontal pole brain tissue. The brain with reduced CVR may have caused a "steal" of blood from near by areas with higher CVRs.

It is surprising that more ischemia was not seen following the brain wound especially near the wound track. With microsphere doses employed, however, we could resolve CBFs down only to 250mg samples. Possibly ischemia occurred more closely adjacent to the missile track undetected by the microsphere method. Autoradiograph techniques, which can resolve CBF in much smaller areas of the brain will answer this question in the future. Nevertheless, the absense of clear cut ischemia about the wound track raises the question as to whether or not reperfusion injury occurs with missile wounds in normotensive animals It would be important to measure CBF at later time points to see whether marked ischemia develops about the wound many hours or days after wounding.

Normal brain function depends upon a "coupling" of blood flow and metabolism.(6) While our experiments have shown that blood flow remains relatively intact in non-fatal missile wounds, we have not yet evaluated metabolism about he wounded brain. If metabolism were depressed an intact blood flow may be supplying non-functioning brain. Again our future autoradiographic experiments in which we will be able to simultaneously measure regional blood flow and metabolism will answer the important question whether blood flow and metabolism remain coupled after wounding.

Regional CBF remained unaffected in large parts of the brain in animals which did not develop high post wounding ICPs. Of particular note is the maintenance of CBF in brain stem structures. This indicates that observed blood pressure pulse and respiratory irregularities seen immediately after missile wounding do not occur as a result of of large areas of medullary ischemia. Other factors as brain stem distortion or the shock wave consequent to missile wounding must be considered to account for these effects.

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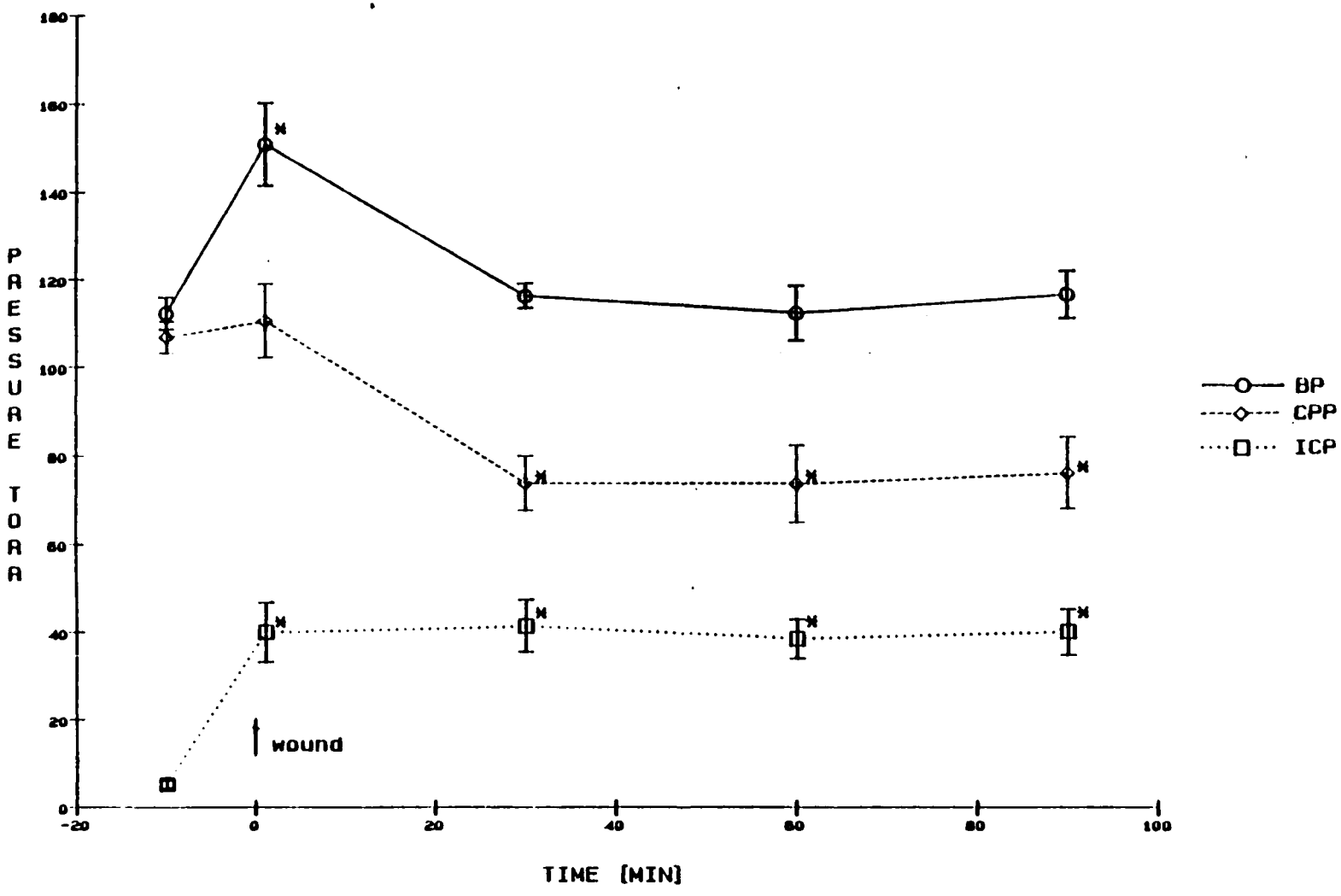
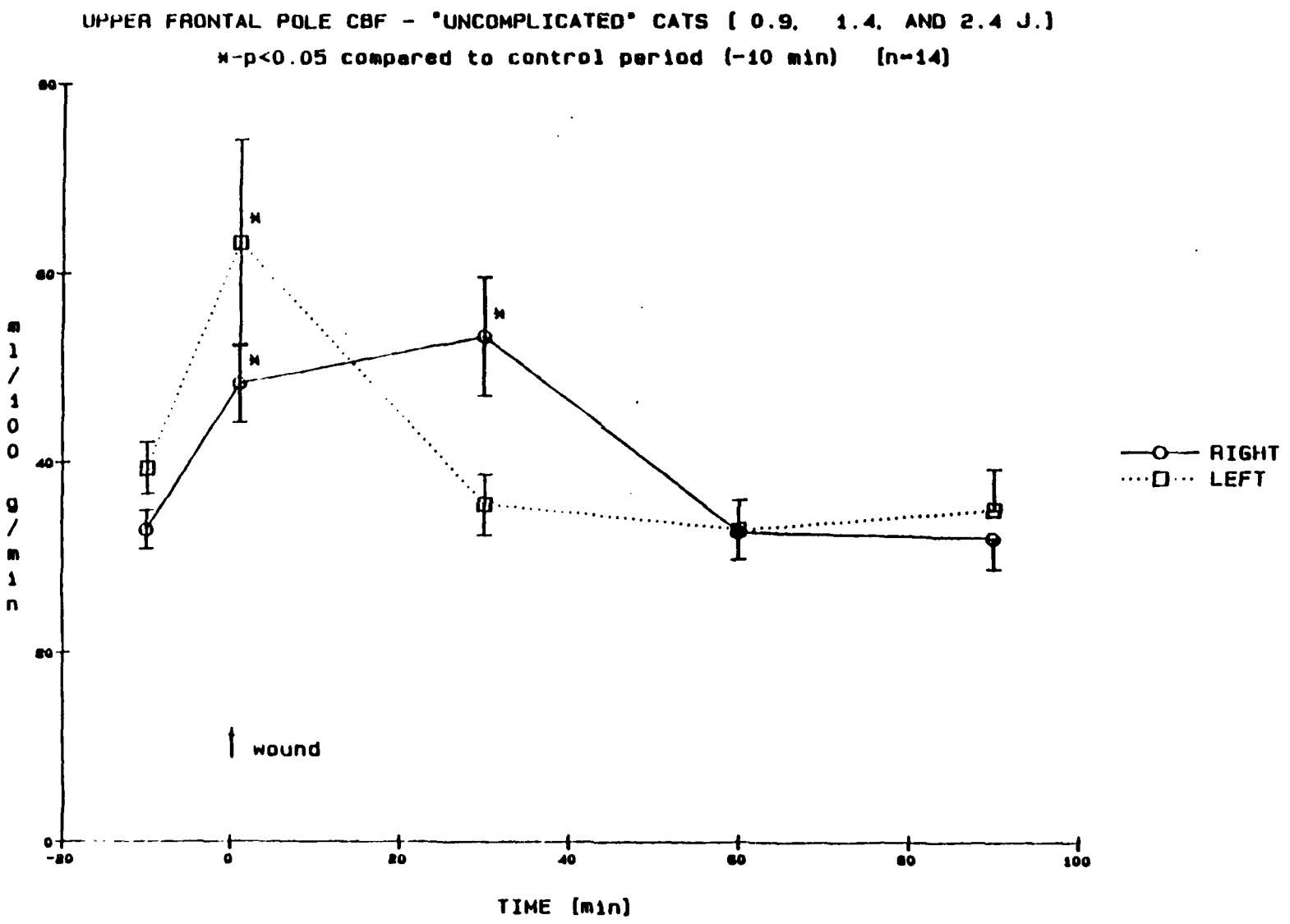
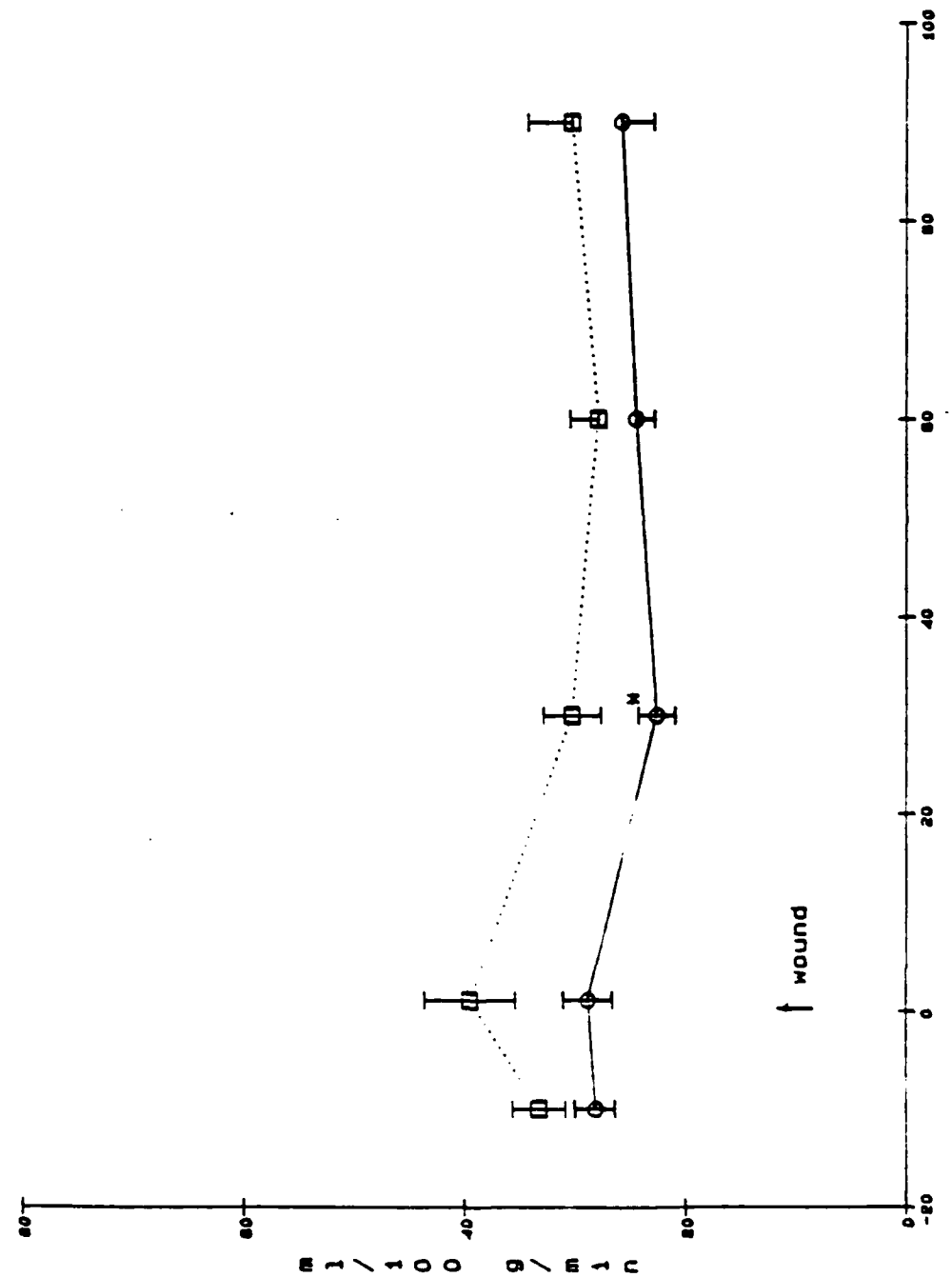
Appendix 1

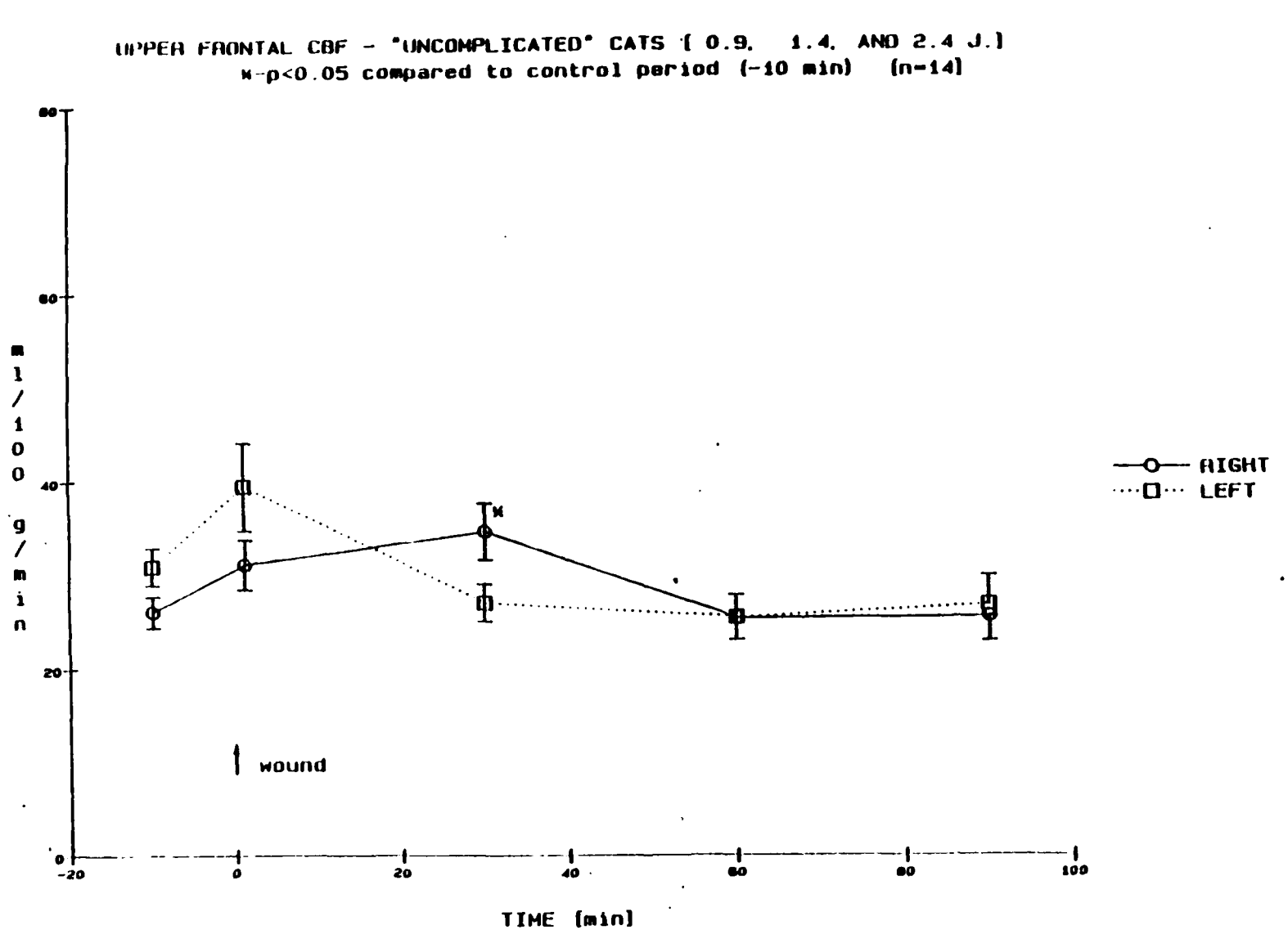
"Uncomplicated" Cats Blood Flow to Individual Brain Regions

BP, ICP, CPP - "UNCOMPLICATED" CATS WOUNDED AT 0.9, 1.4, AND 2.4 J.
*-p<0.05 compared to control period (-10 min) [n=14]

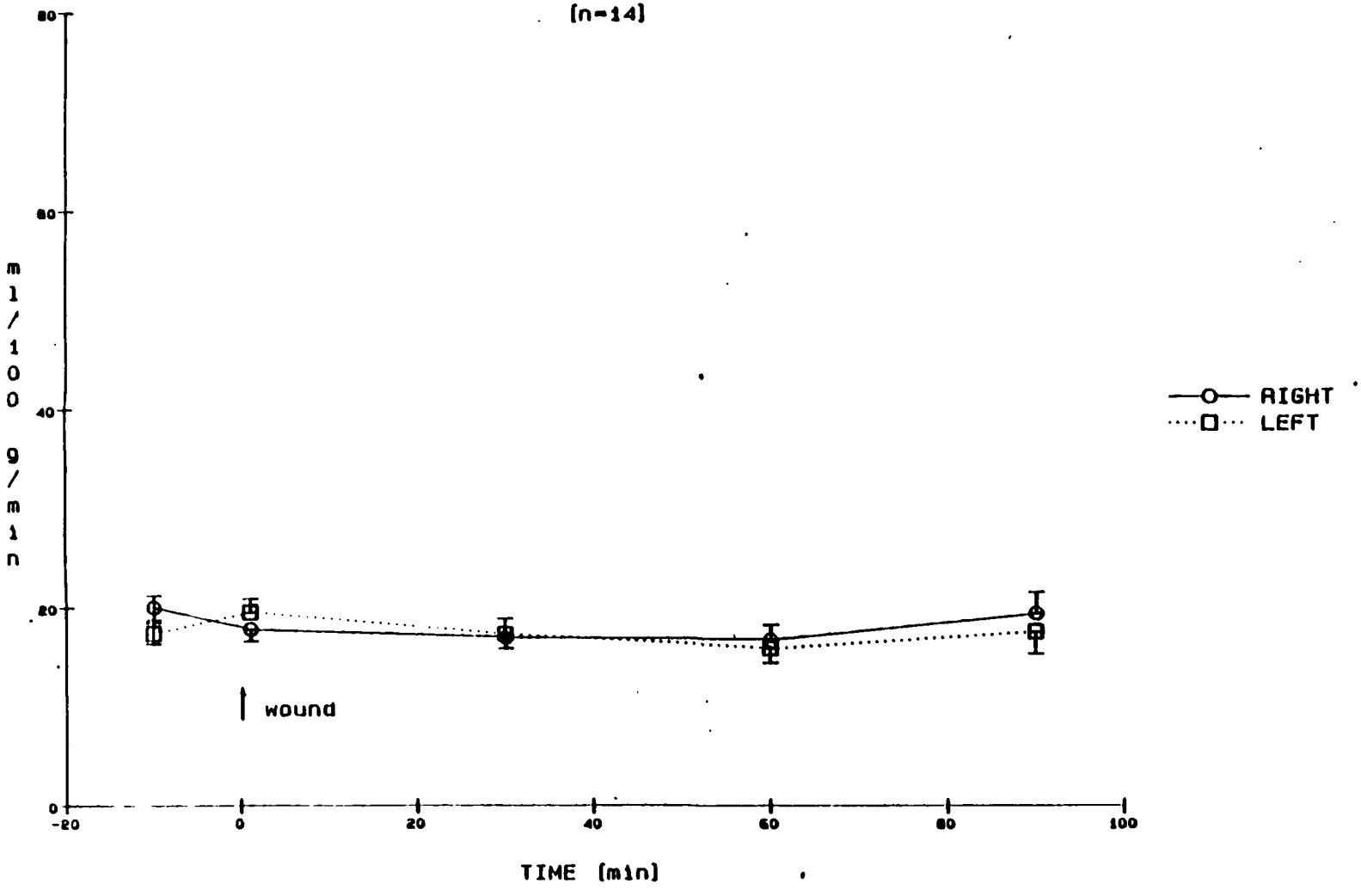


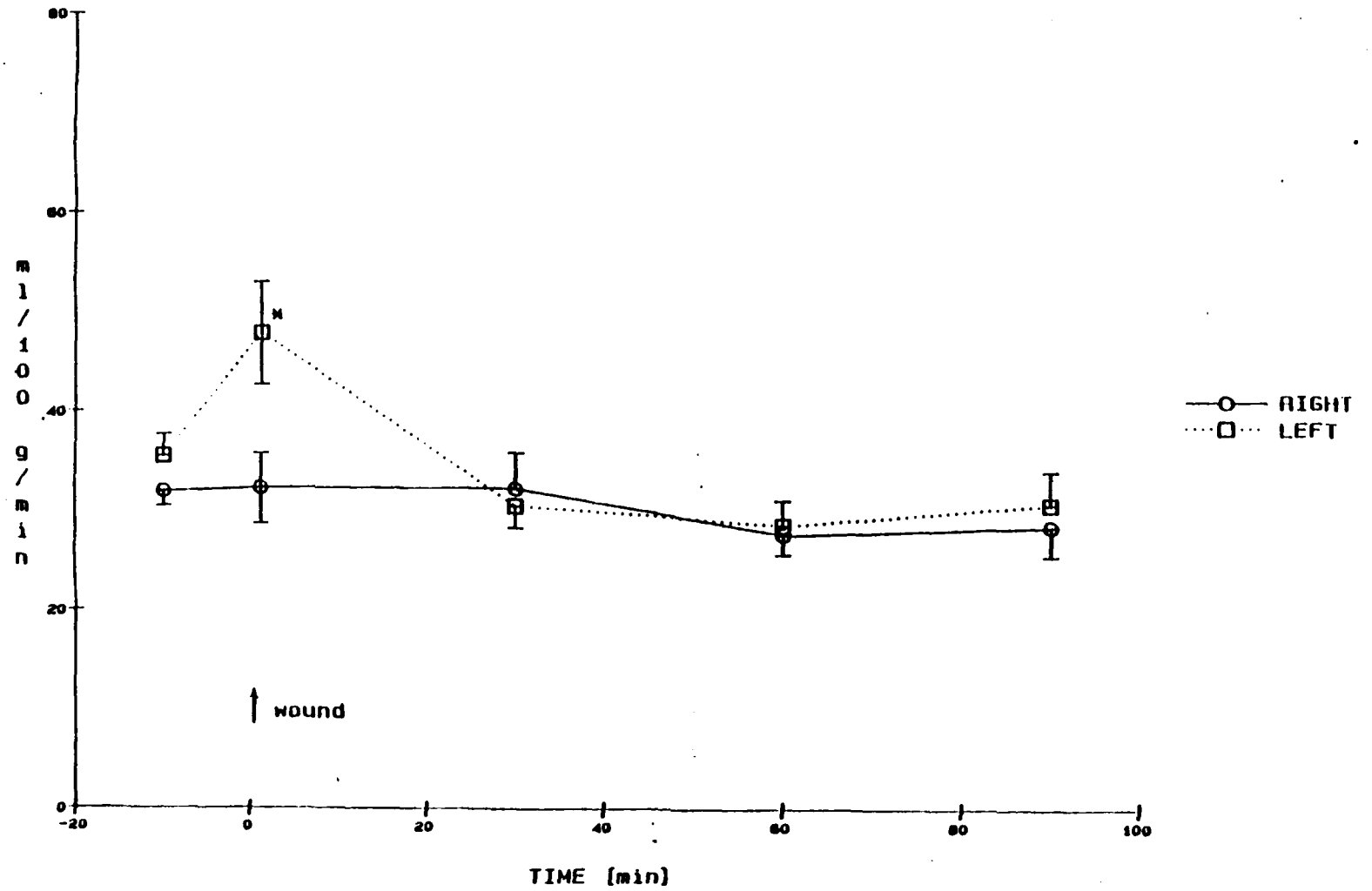

UPPER FRONTAL POLE CBF - "UNCOMPLICATED" CATS [0.9, 1.4, AND 2.4 J.]
*-p<0.05 compared to control period (-10 min) [n=14]
ml/100 g/min
0
20
40
60
80
-20
0
20
40
60
80
100
wound
TIME [min]
RIGHT
LEFT


LOWER FRONTAL POLE CBF - "UNCOMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)
M-p<0.05 compared to control period (-10 min) (n=14)
RIGHT
LEFT
ml/100 g/min
TIME (min)
wound
M
80
60
40
20
0
-20
100


UPPER FRONTAL CBF - "UNCOMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)
*-p<0.05 compared to control period (-10 min) (n=14)
ml/100 g/min
80
60
40
20
0
-20
0
20
40
60
80
100
*
wound
RIGHT
LEFT
TIME (min)

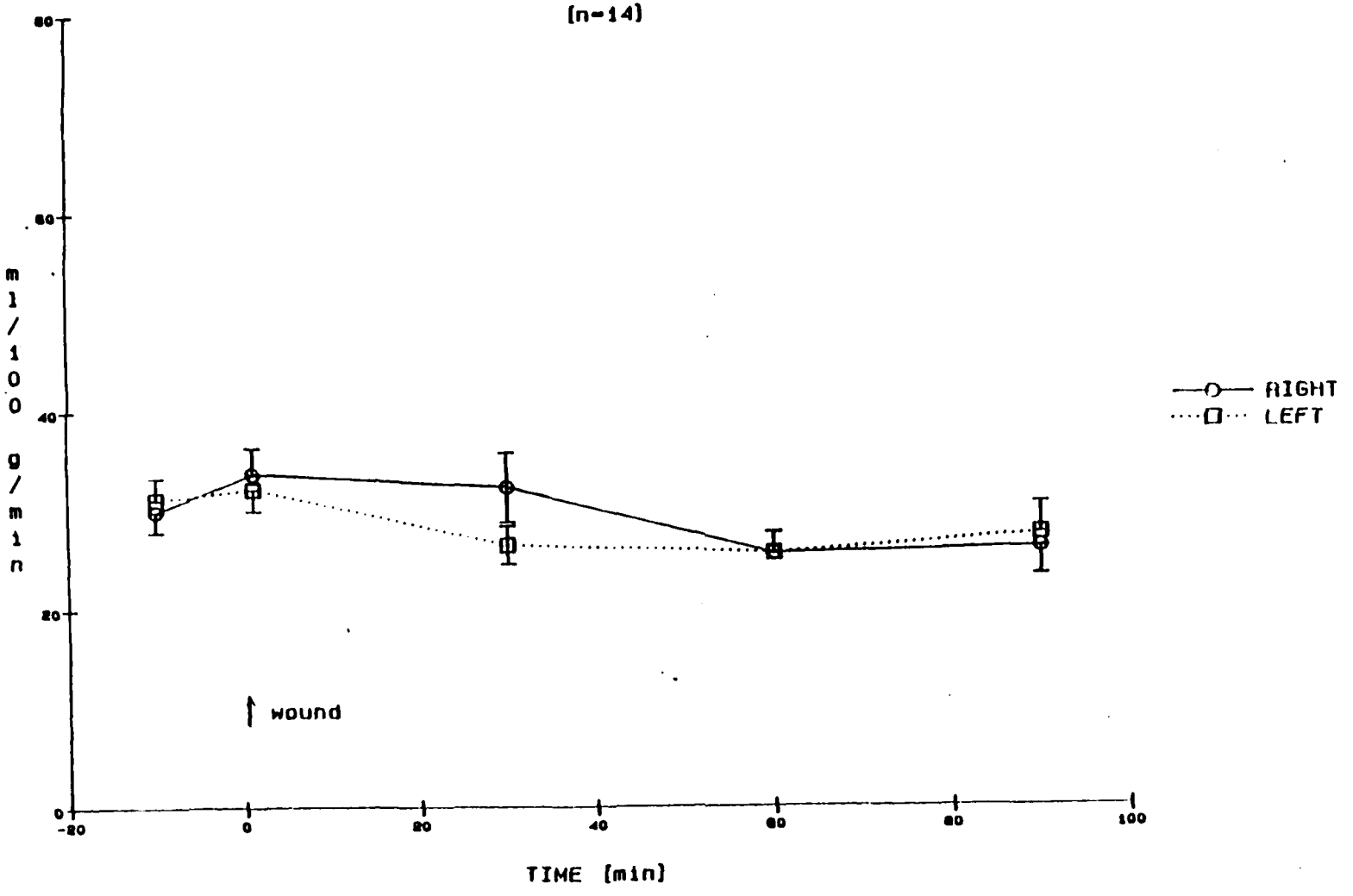
LOWER FRONTAL-TEMPORAL CBF - "UNCOMPLICATED" CATS [0.9, 1.4, AND 2.4 J.]

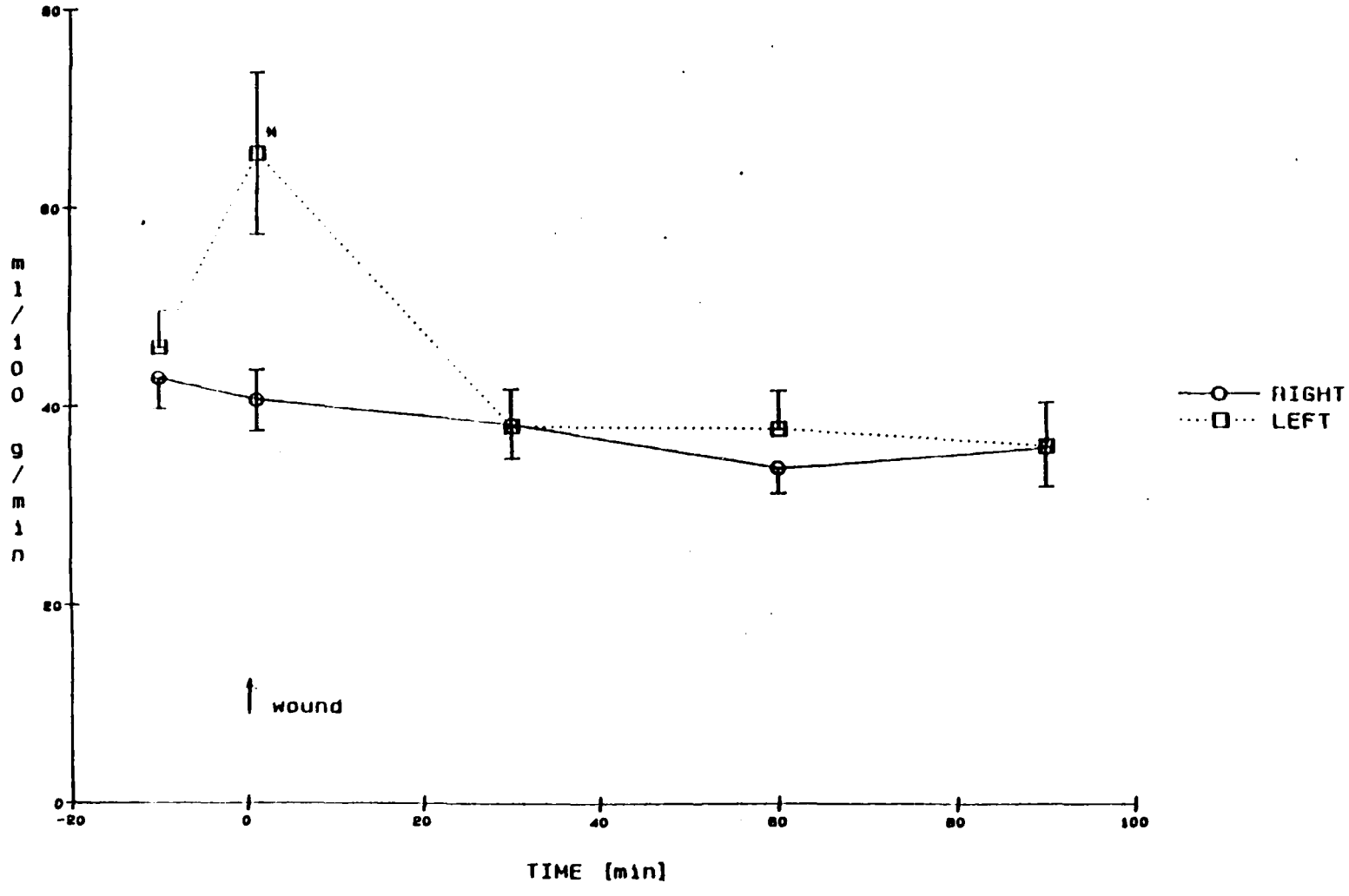



PARIETAL CBF - "UNCOMPLICATED" CATS (0.9, 1.4 AND 2.4 J..
*-p<0.05 compared to control period (-10 min) (n=14)
ml/100 g/min
80
60
40
20
0
*
wound
-20
0
20
40
60
80
100
TIME (min)
RIGHT
LEFT

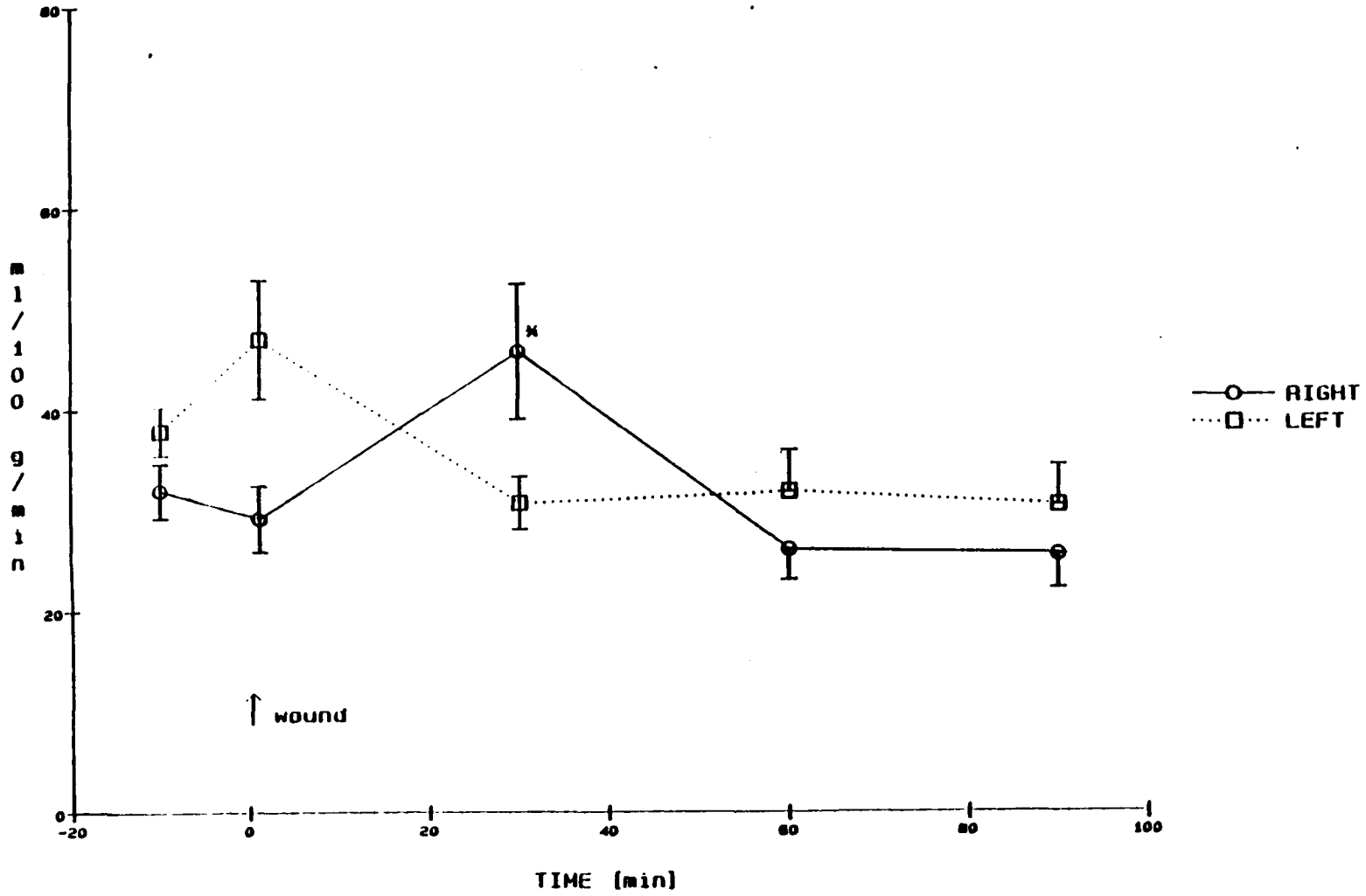
TEMPORAL CBF - "UNCOMPLICATED" CATS [0.9, 1.4, AND 2.4 J.]

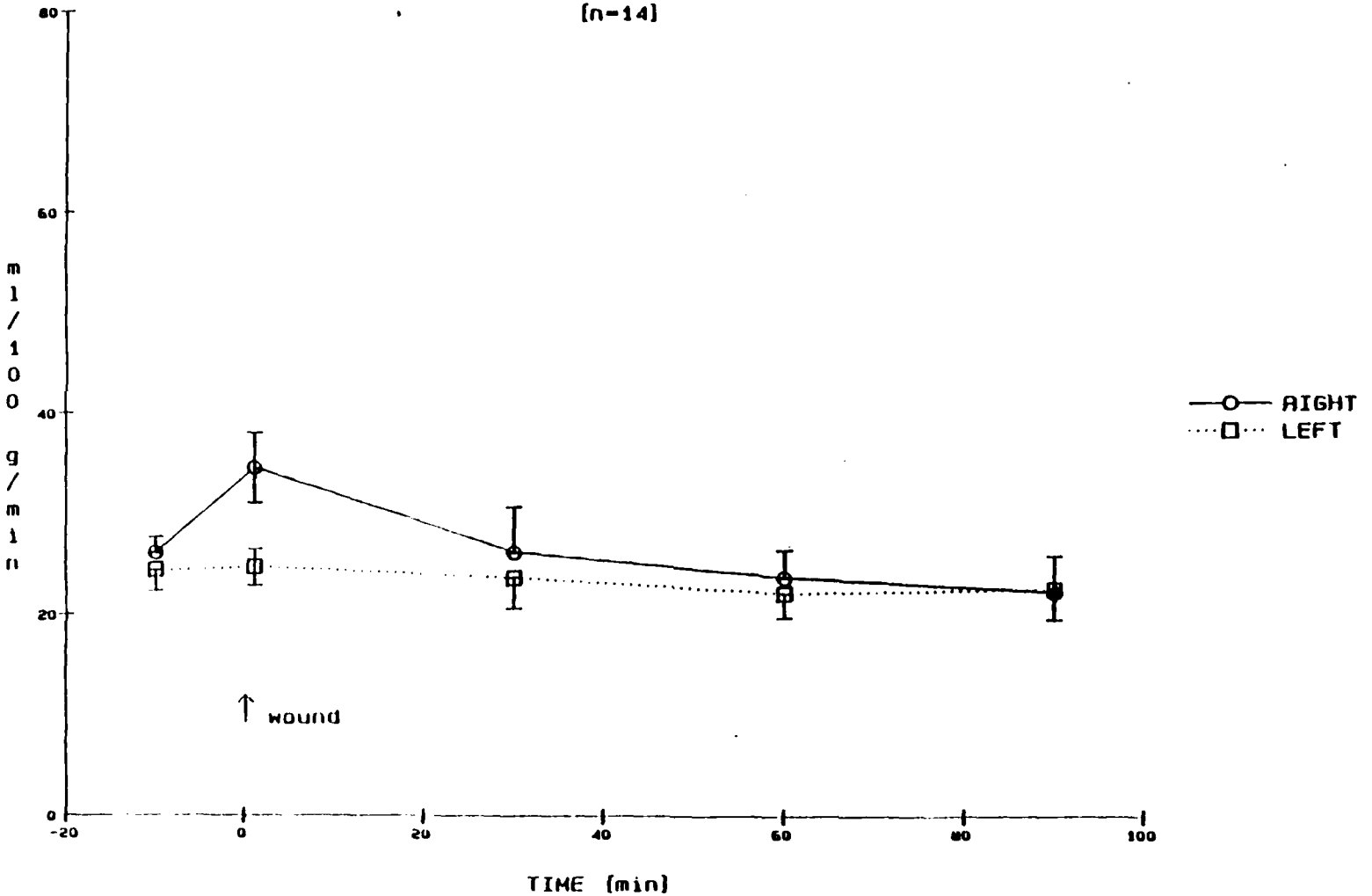
(n=14)



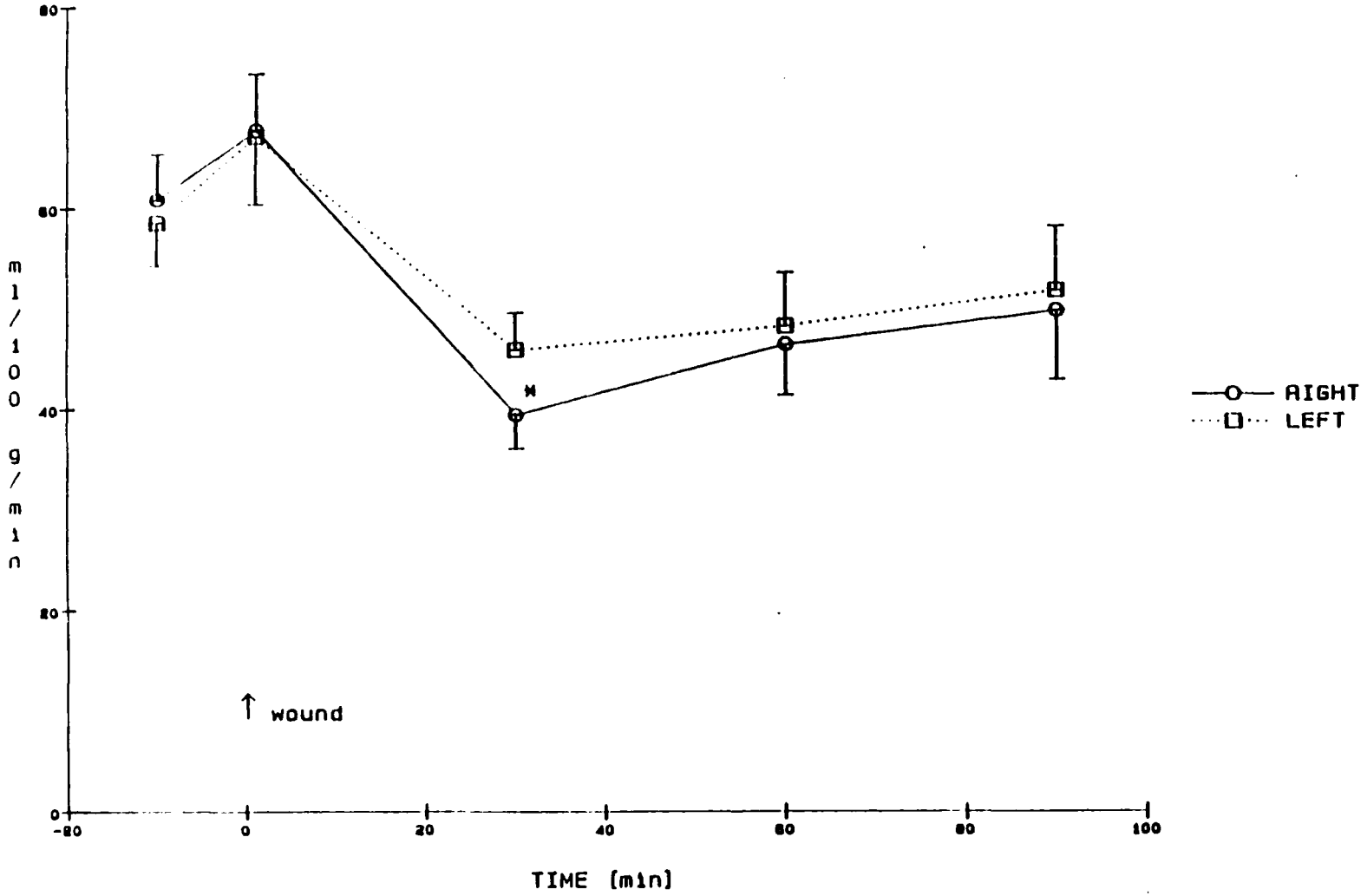

UPPER OCCIPITAL POLE CBF - "UNCOMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)
*-p<0.05 compared to control period (-10 min) (n=14)
ml/100 g/min
80
60
40
20
0
*
wound
-20
0
20
40
60
80
100
TIME (min)
RIGHT
LEFT

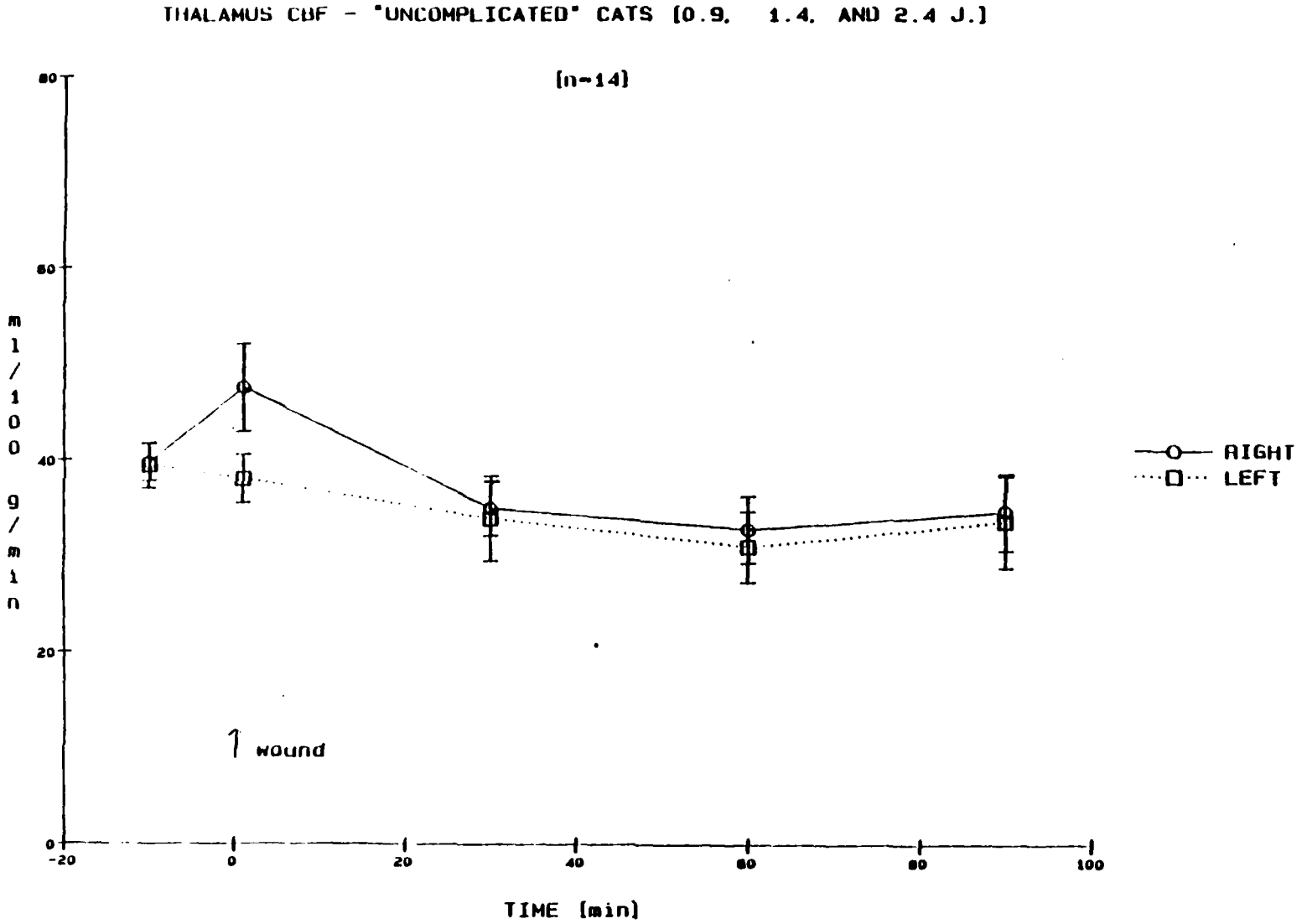
LOWER OCCIPITAL AREA CBF - "UNCOMPLICATED" CATS [0.9, 1.4, AND 2.4 J.]
*-p<0.05 compared to control period (-10 min) (n=14)




HIPPOCAMPUS CBF - "UNCOMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)
(n=14)
ml/100 g/min
80
60
40
20
0
-20
0
20
40
60
80
100
TIME (min)
wound
RIGHT
LEFT

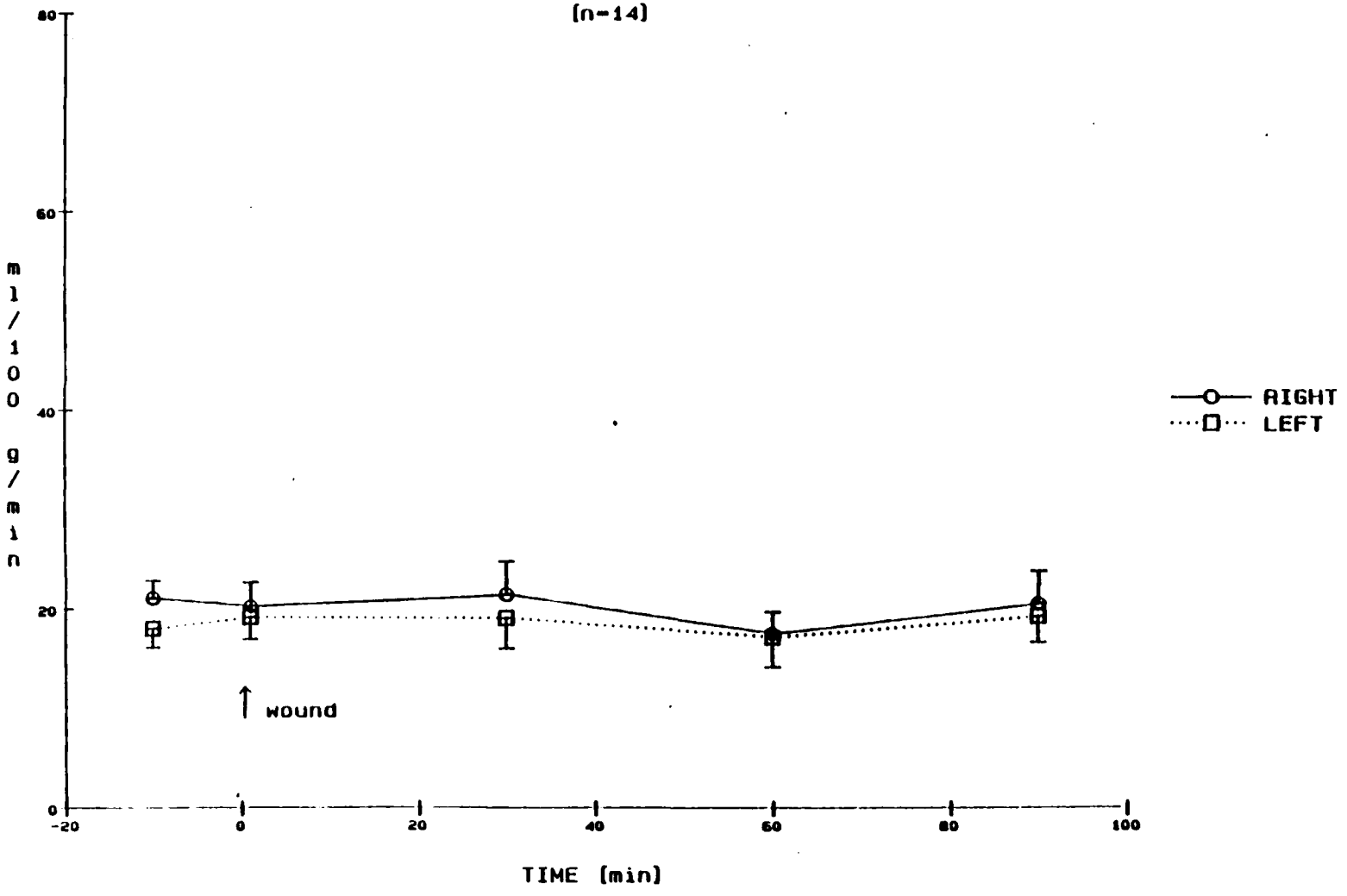
CAUDATE CBF - "UNCOMPLICATED" CATS - [0.9, 1.4, AND 2.4 J.]
*-p<0.05 compared to control period (-10 min) [n=14]




THALAMUS CBF - "UNCOMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)
(n=14)
ml/100 g/min
80
60
40
20
0
-20
0
20
40
60
80
100
TIME (min)
1 wound
RIGHT
LEFT

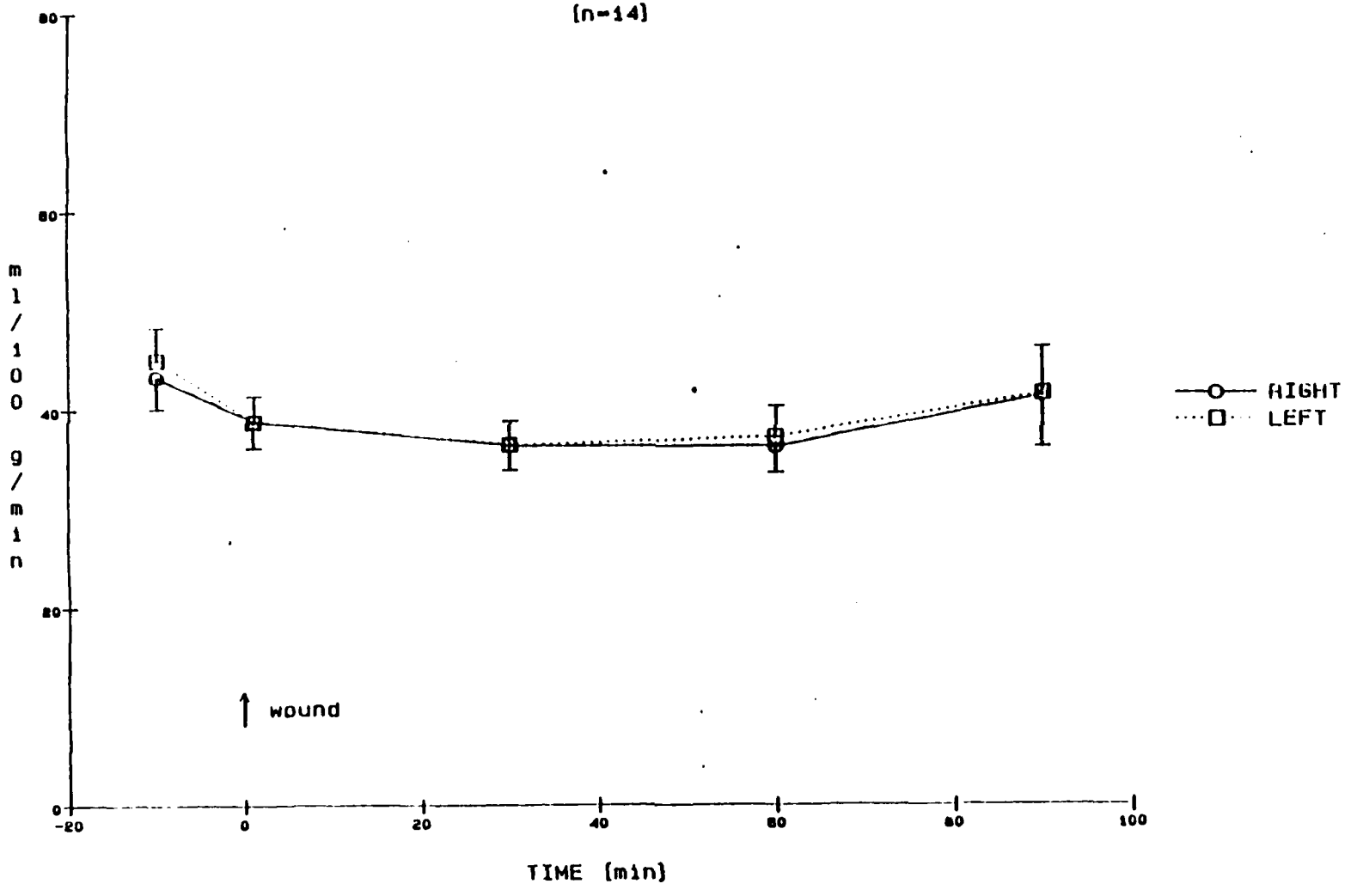
HYPOTHALAMUS CBF - "UNCOMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)

(n=14)

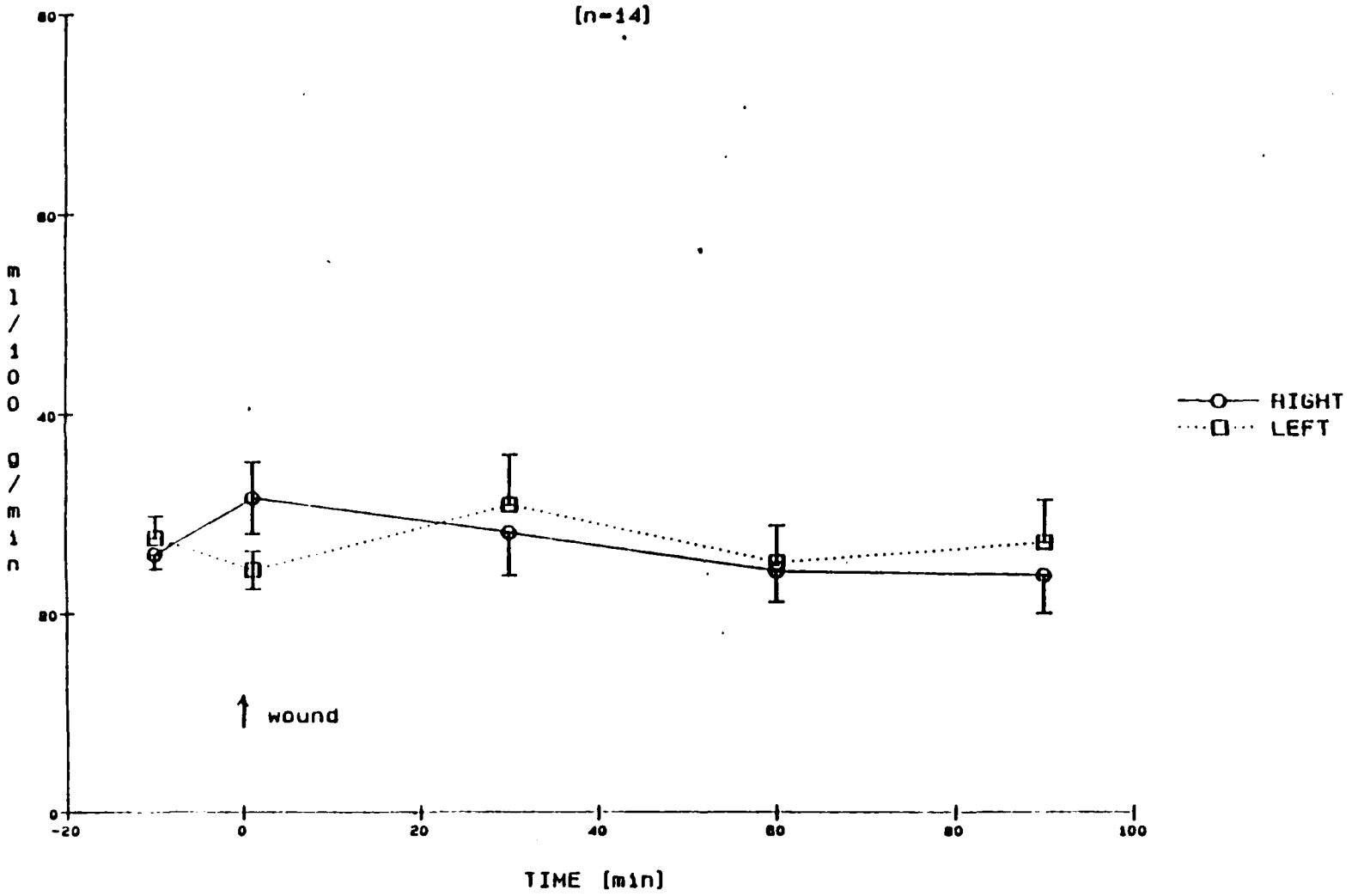


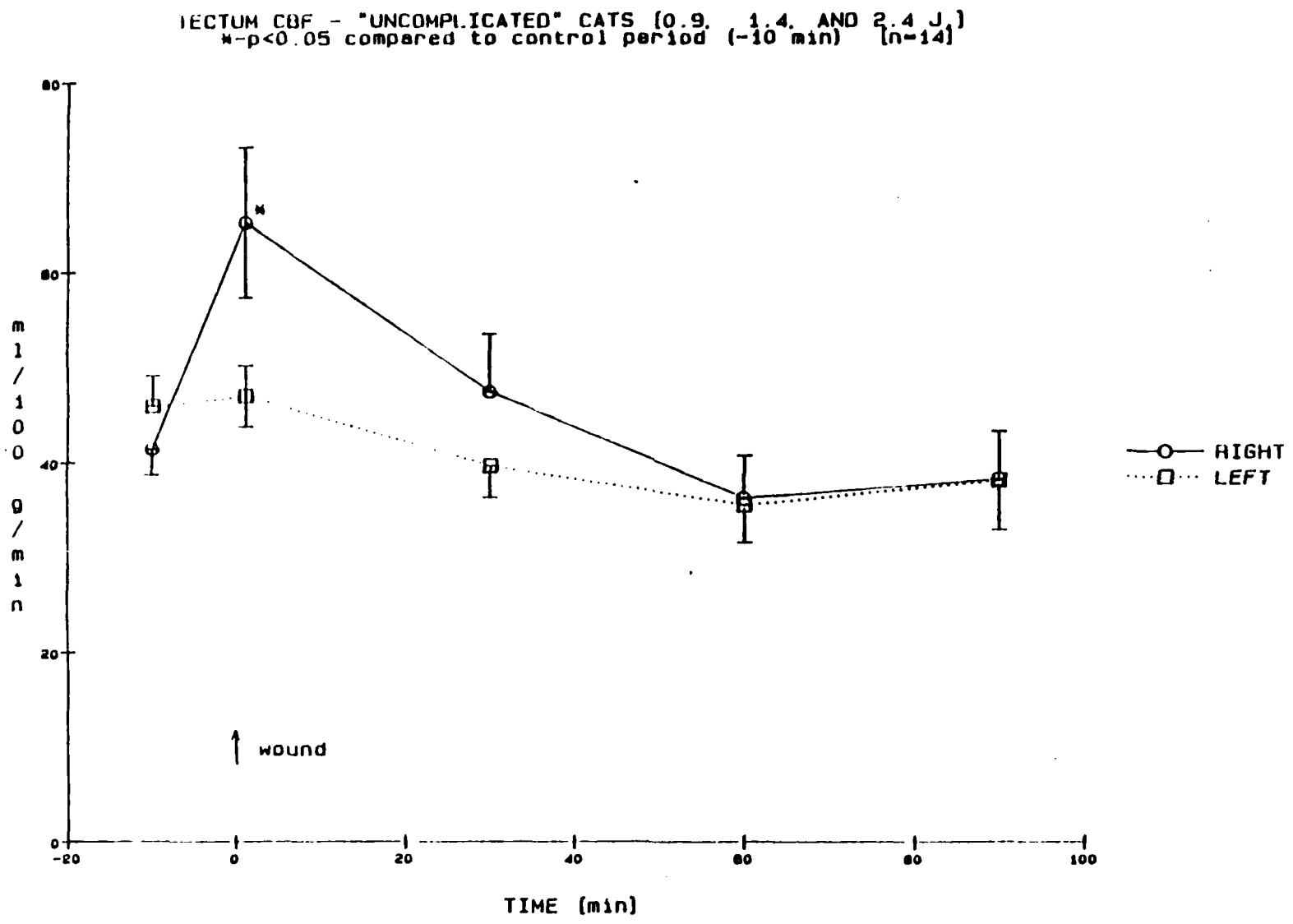
CEREBELLUM CBF - "UNCOMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)

(n=14)

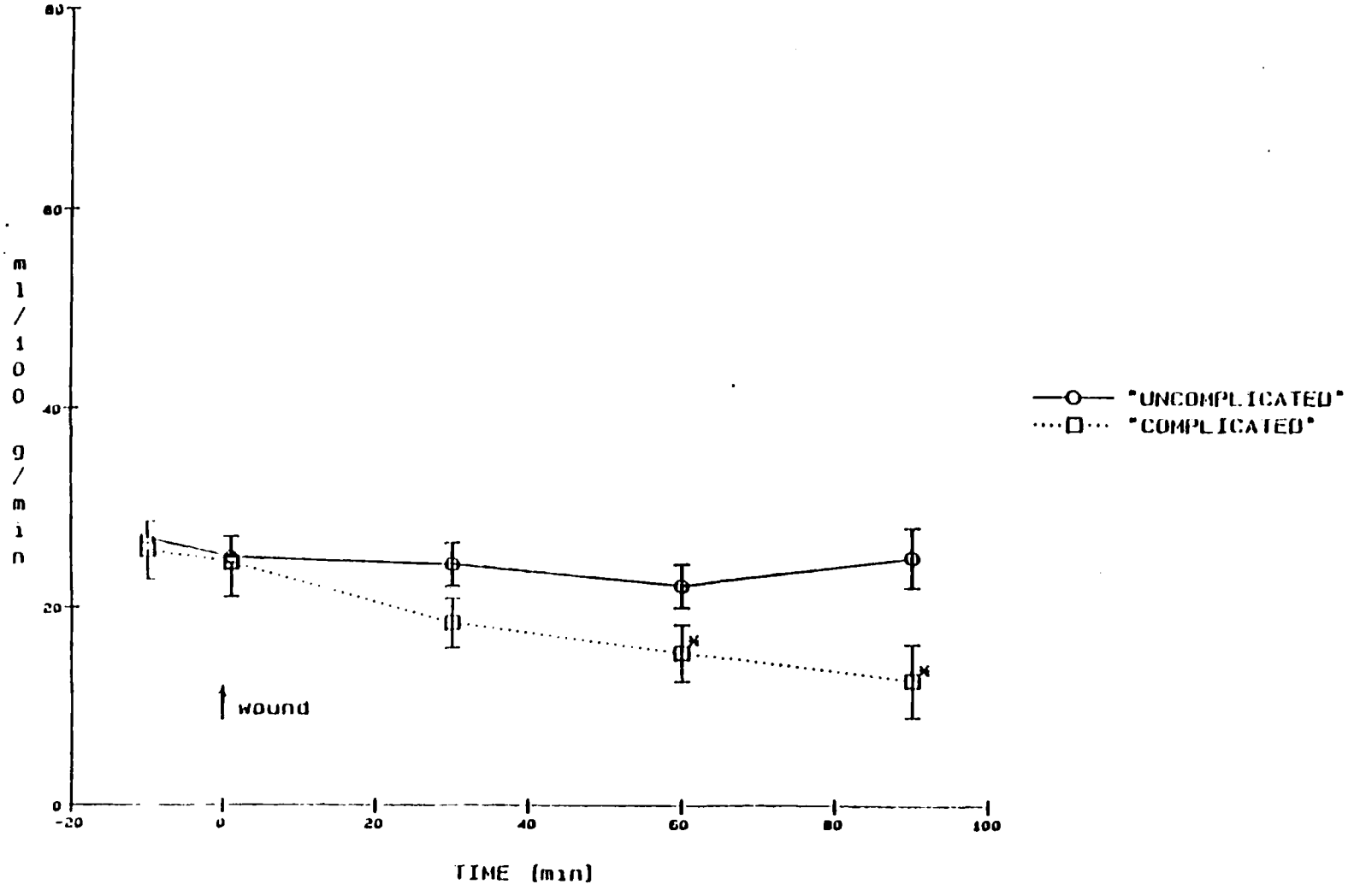


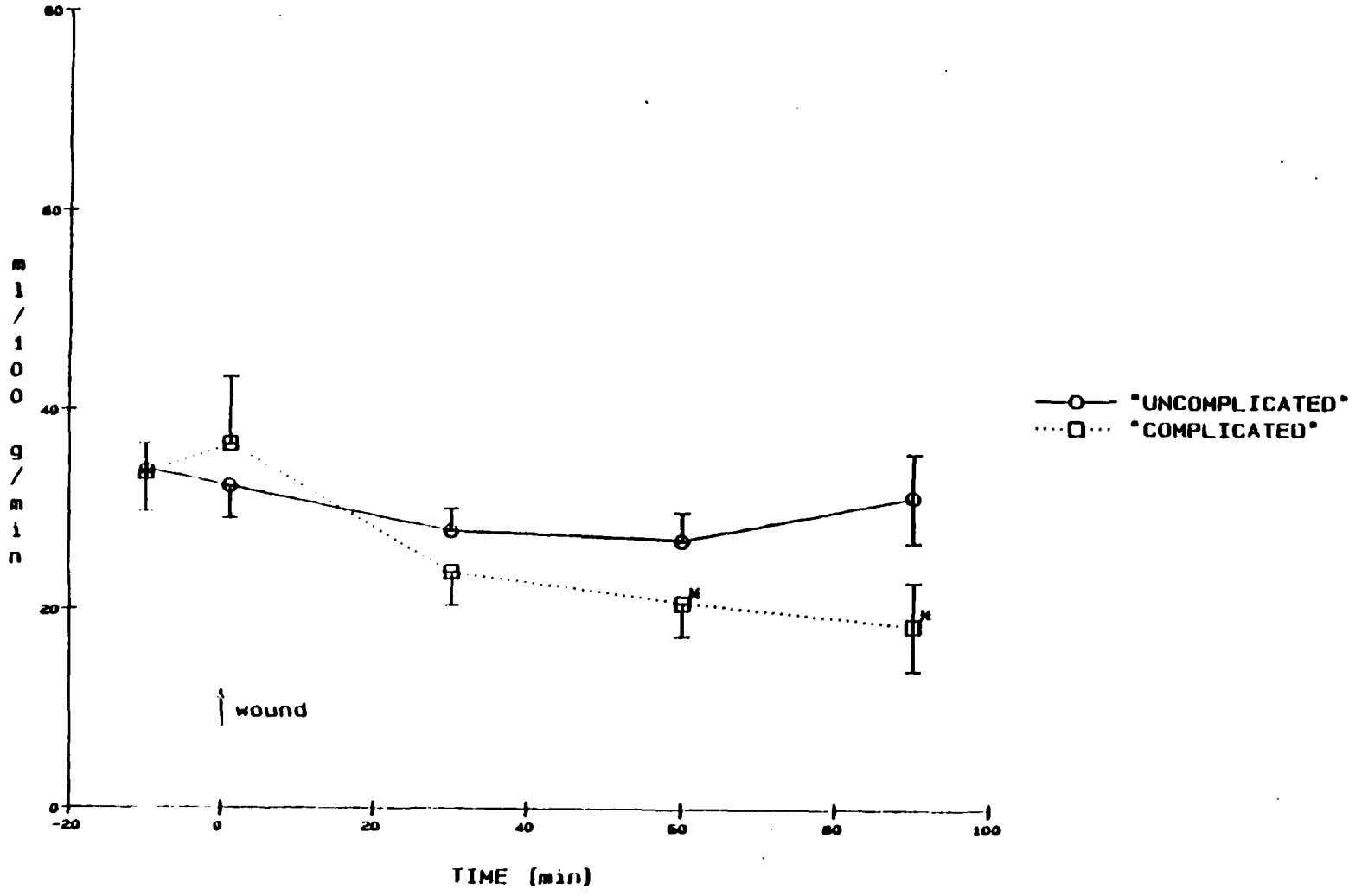
MESENCEPHALON CBF - "UNCOMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)

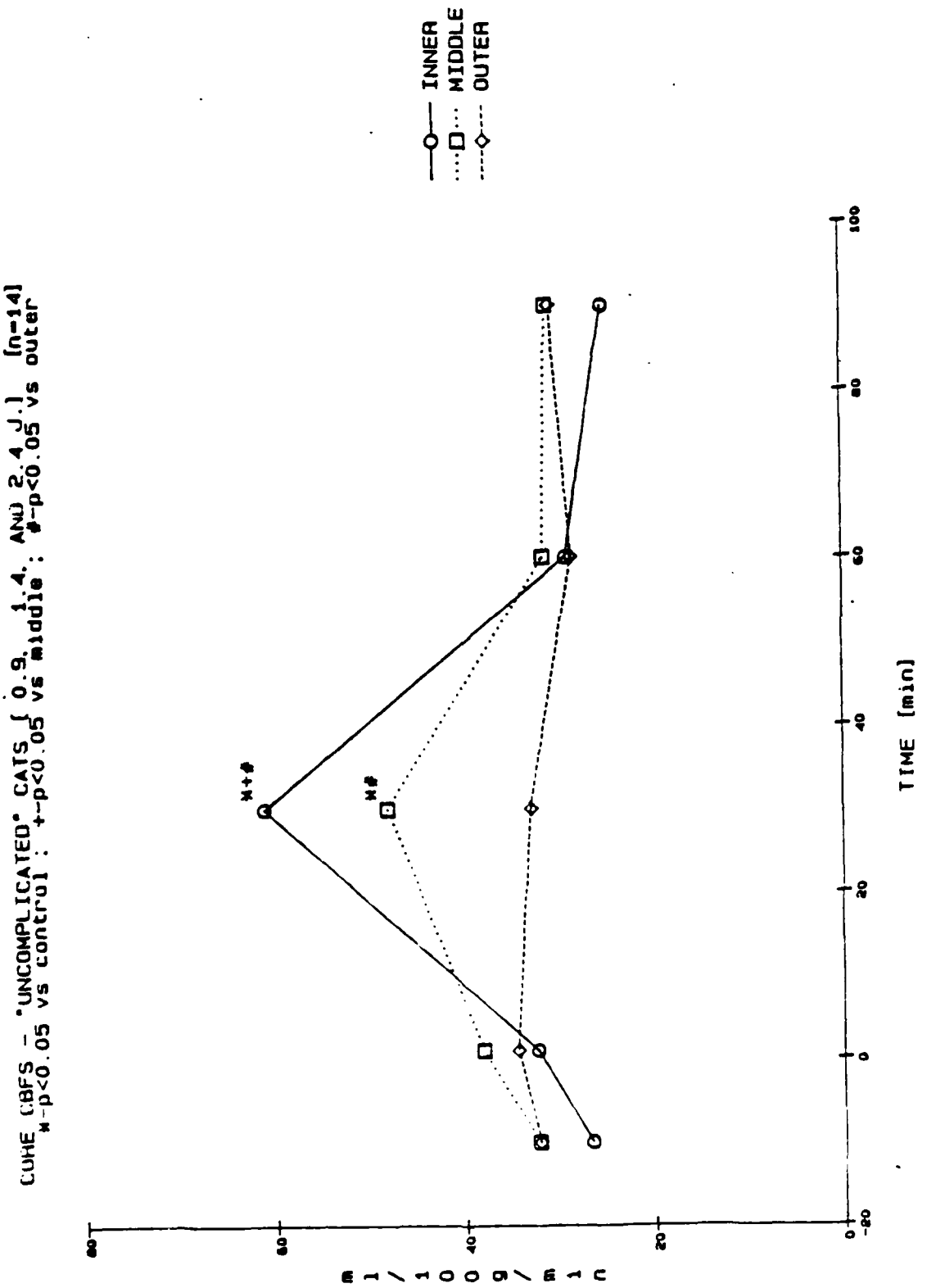


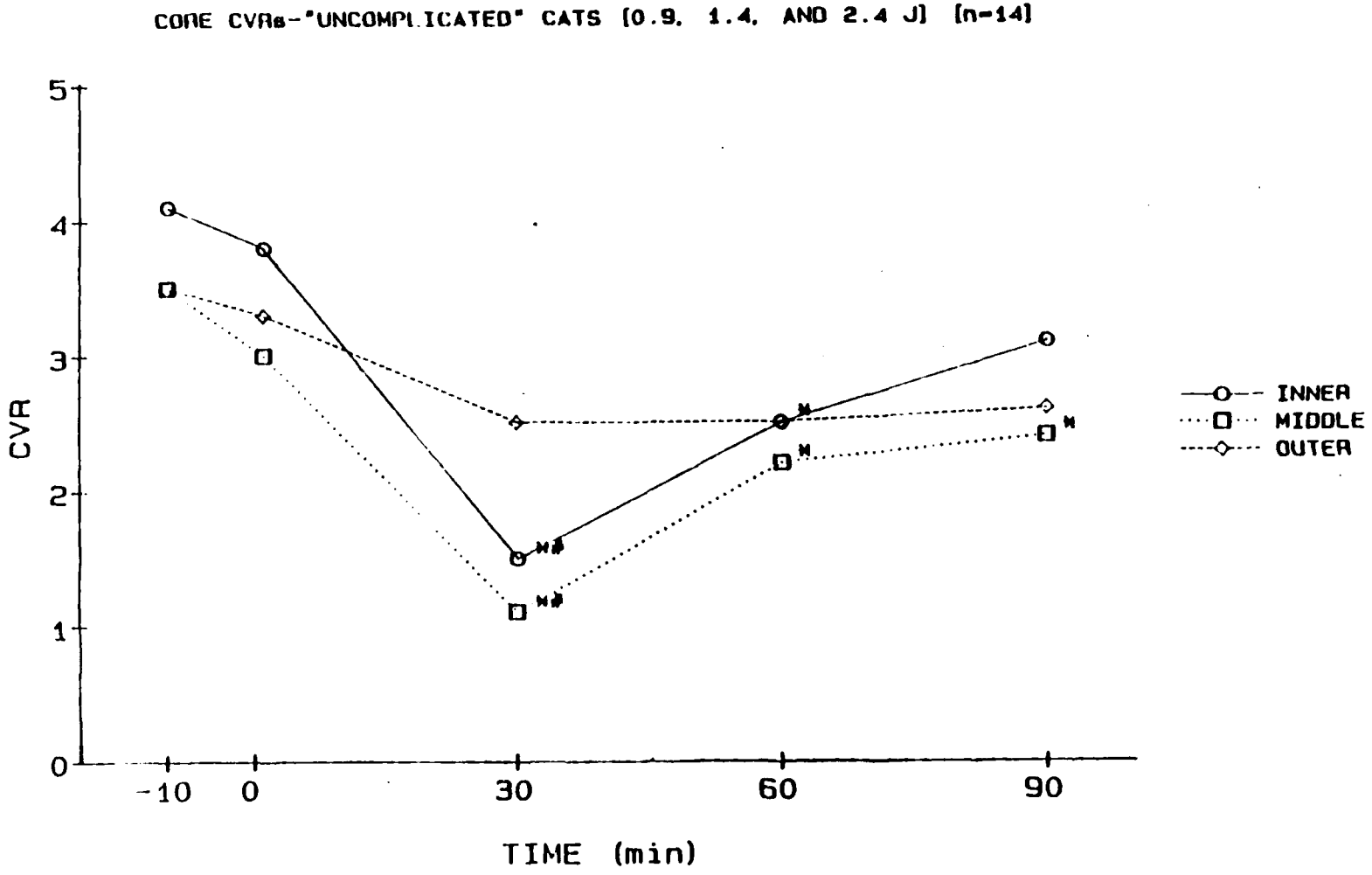

TECTUM CBF - "UNCOMPLICATED" CATS (0.9, 1.4, AND 2.4 J)
*-p<0.05 compared to control period (-10 min) (n=14)
ml/100 g/min
80
60
40
20
0
*
wound
-20
0
20
40
60
80
100
TIME (min)
RIGHT
LEFT

PONS CBF - CATS WOUNDED AT 0.9, 1.4, AND 2.4 J.
*-p<0.05 compared to control period (-10 min)




MEDULLA CBF - CATS WOUNDED AT 0.9, 1.4, AND 2.4 J.
M-p<0.05 compared to control period (-10 min)
ml/100 g/min
0
20
40
60
80
-20
0
20
40
60
80
100
wound
TIME (min)
"UNCOMPLICATED"
"COMPLICATED"

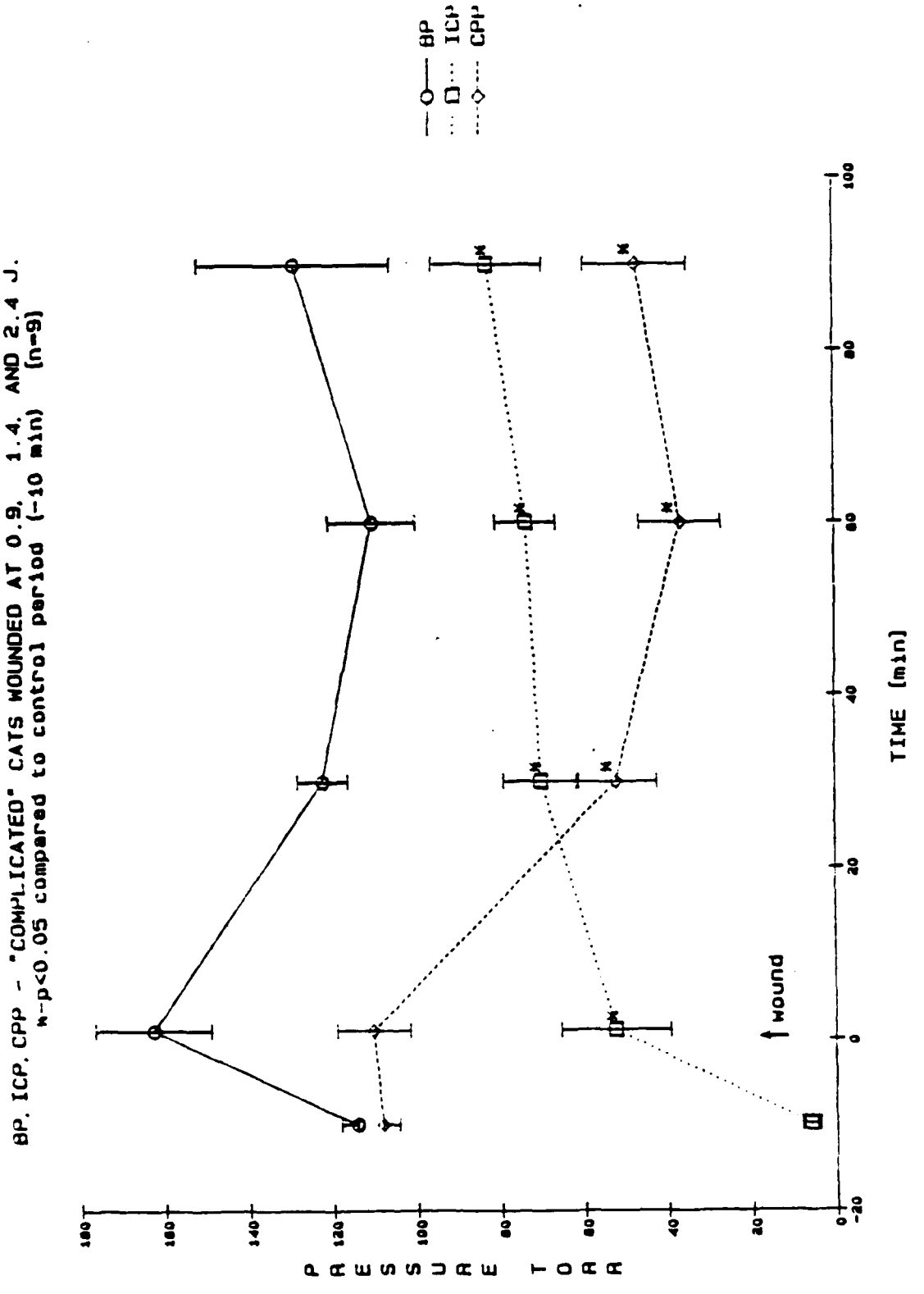

CUHE CBFS - "UNCOMPLICATED" CATS [0.9, 1.4, AND 2.4 U.] [n=14]
M-p<0.05 vs control : +-p<0.05 vs middle : #-p<0.05 vs outer
INNER
MIDDLE
OUTER
M+#
M#
ml/100g/min
TIME [min]
0
20
40
60
80
100
-20



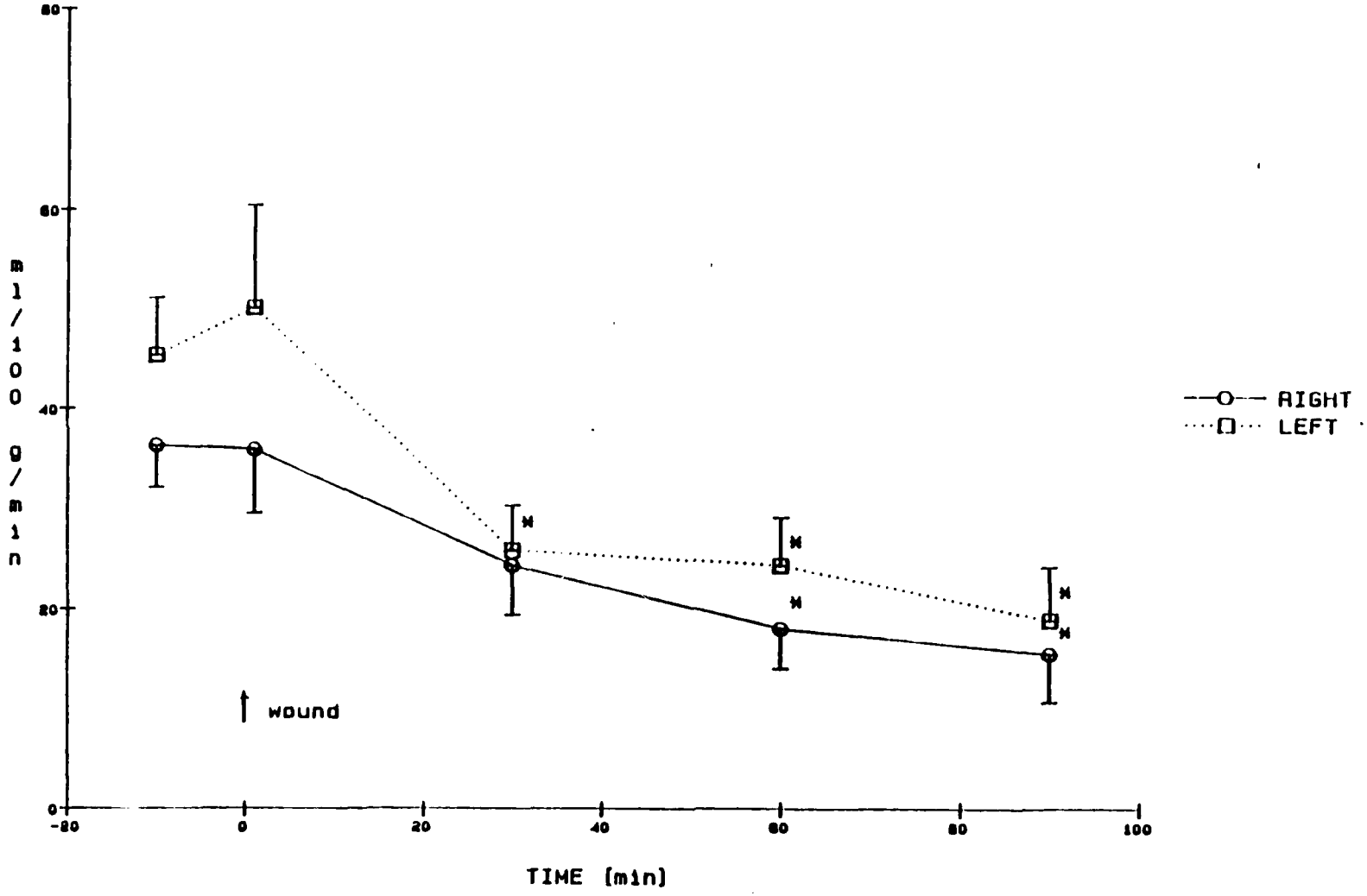
M-p<0.05 vs control; #-p<0.05 vs outer

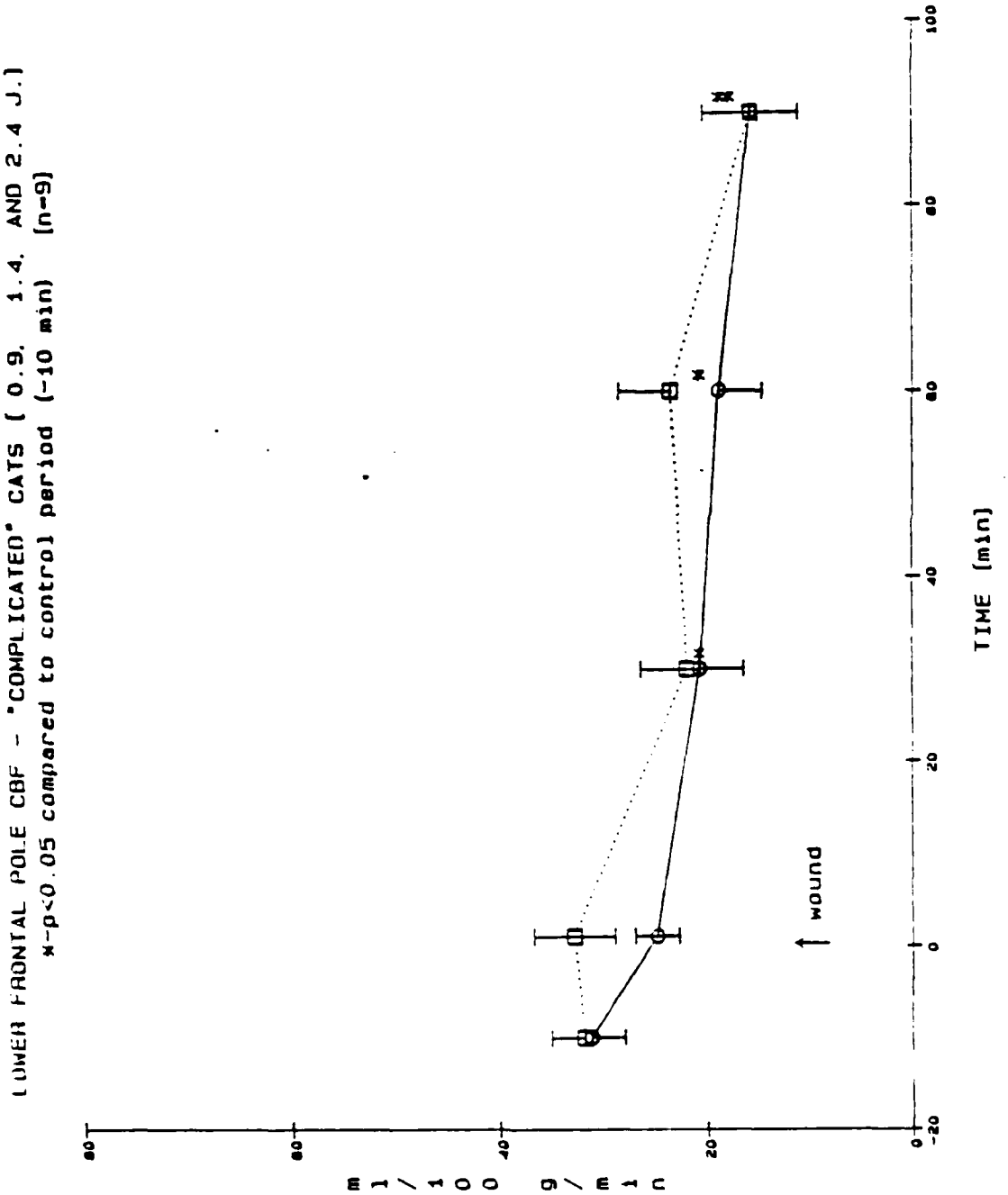
Appendix 2

"Complicated" Cats Blood Flow to Individual Brain Regions

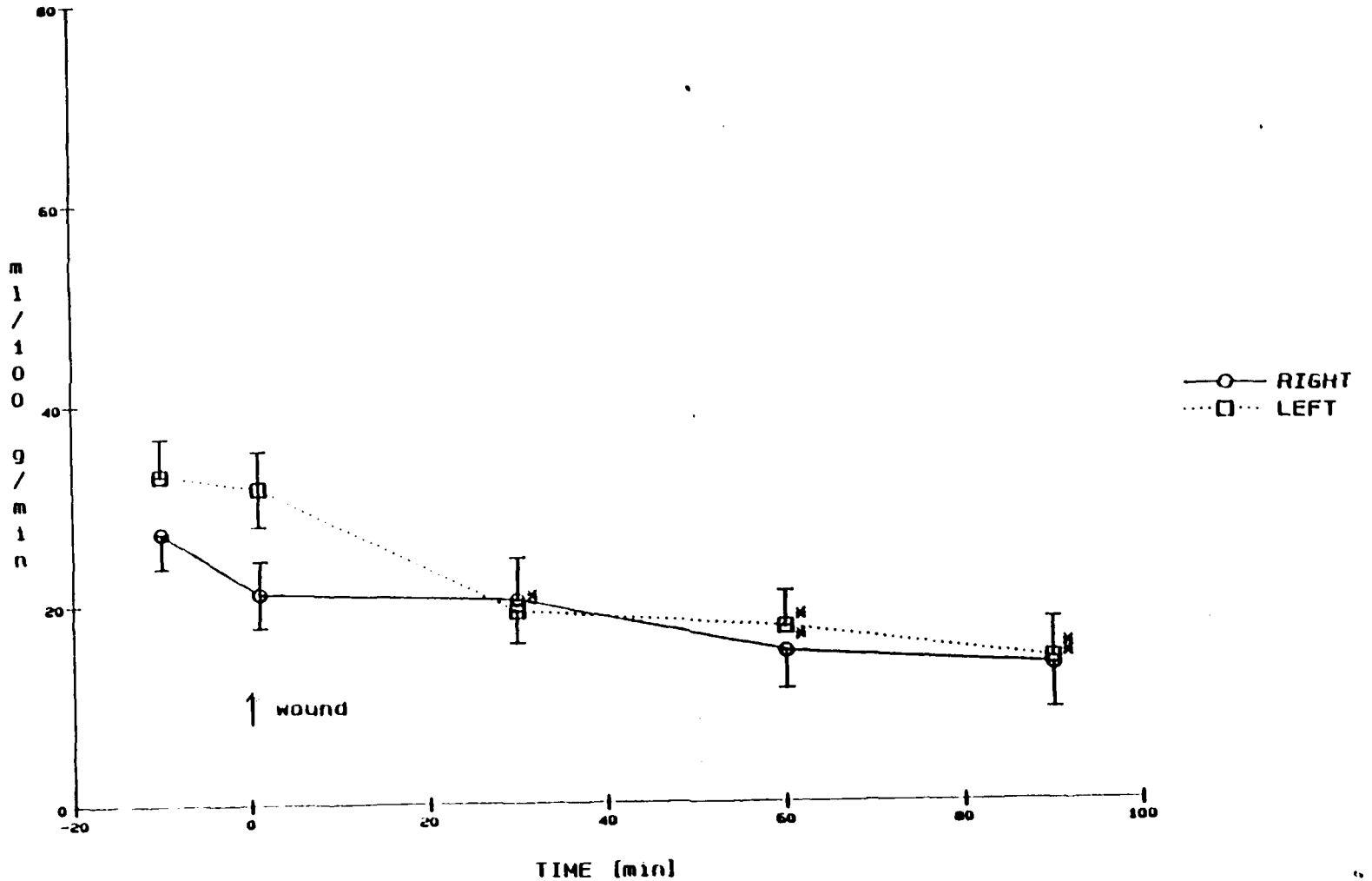

BP, ICP, CPP - "COMPLICATED" CATS WOUNDED AT 0.9, 1.4, AND 2.4 J.
*-p<0.05 compared to control period (-10 min) (n=9)
BP
ICP
CPP
PRESSURE TORR
TIME (min)
wound

UPPER FRONTAL POLE CBF - "COMPLICATED" CATS [0.9, 1.4 AND 2.4 J.]
M-p<0.05 compared to control period (-10 min) (n=9)

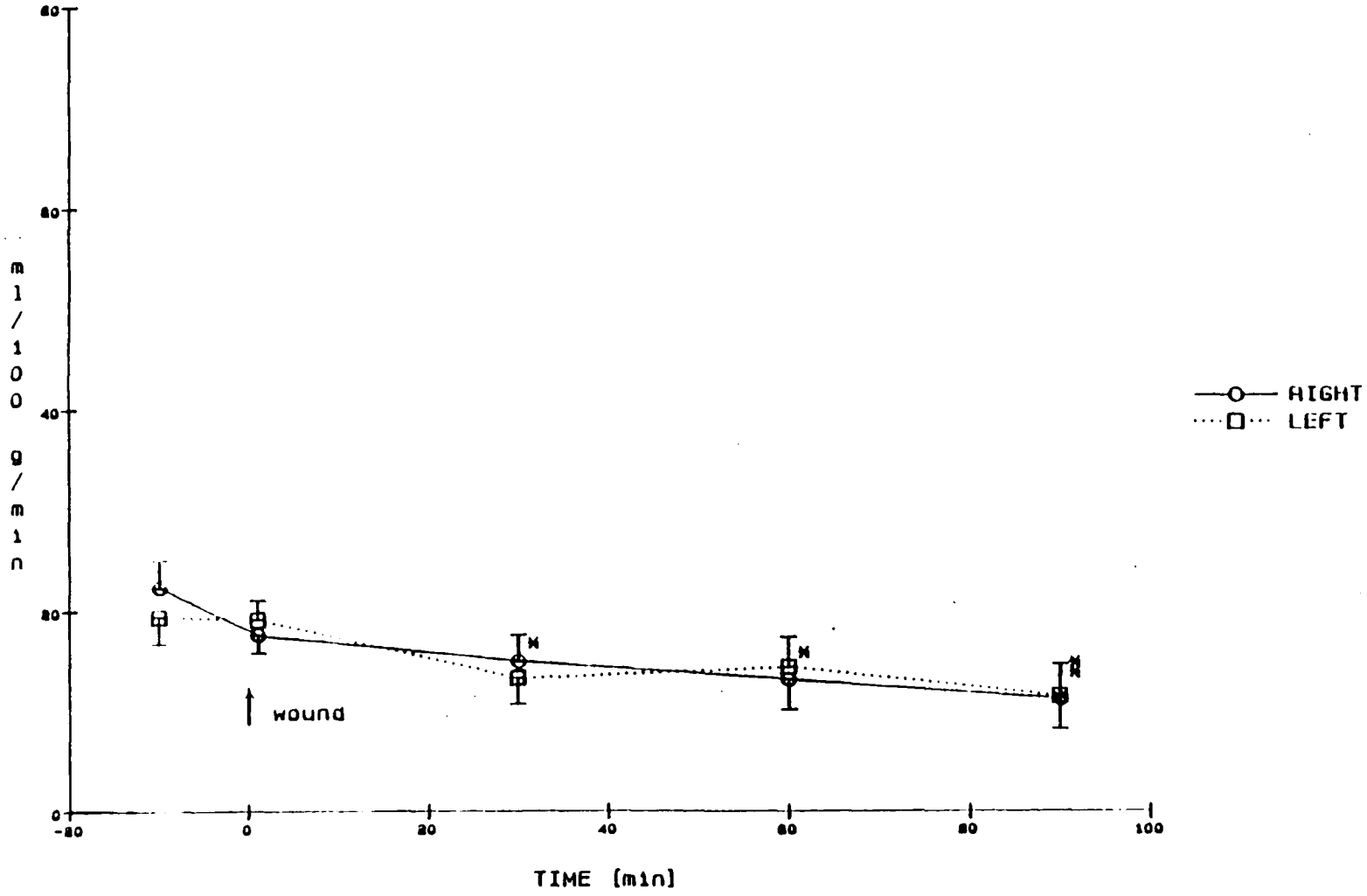


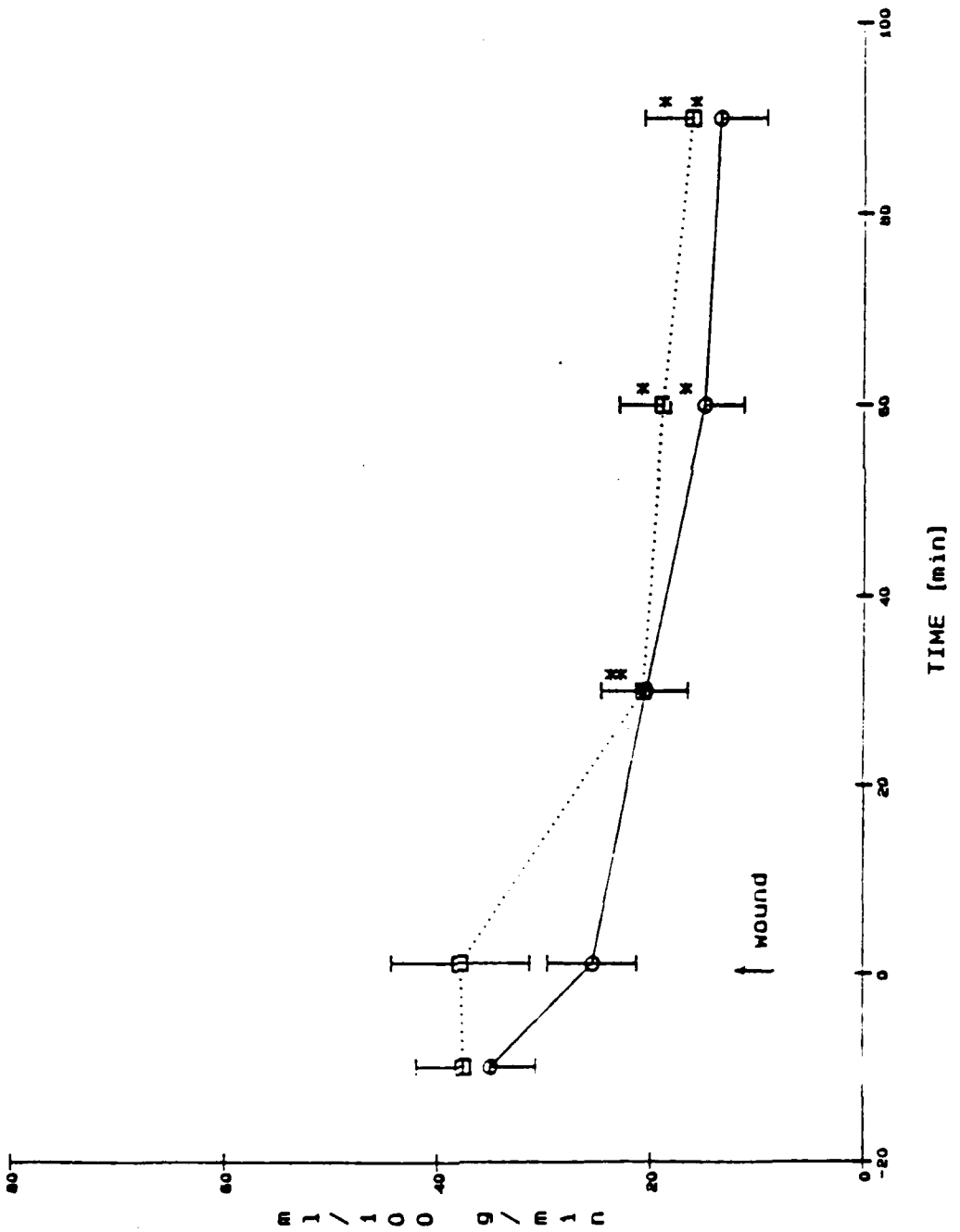

LOWER FRONTAL POLE CBF - "COMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)
*-p<0.05 compared to control period (-10 min) (n=9)
RIGHT
LEFT
wound
TIME (min)
ml/100 g/min
80
60
40
20
0
-20
0
20
40
60
80
100

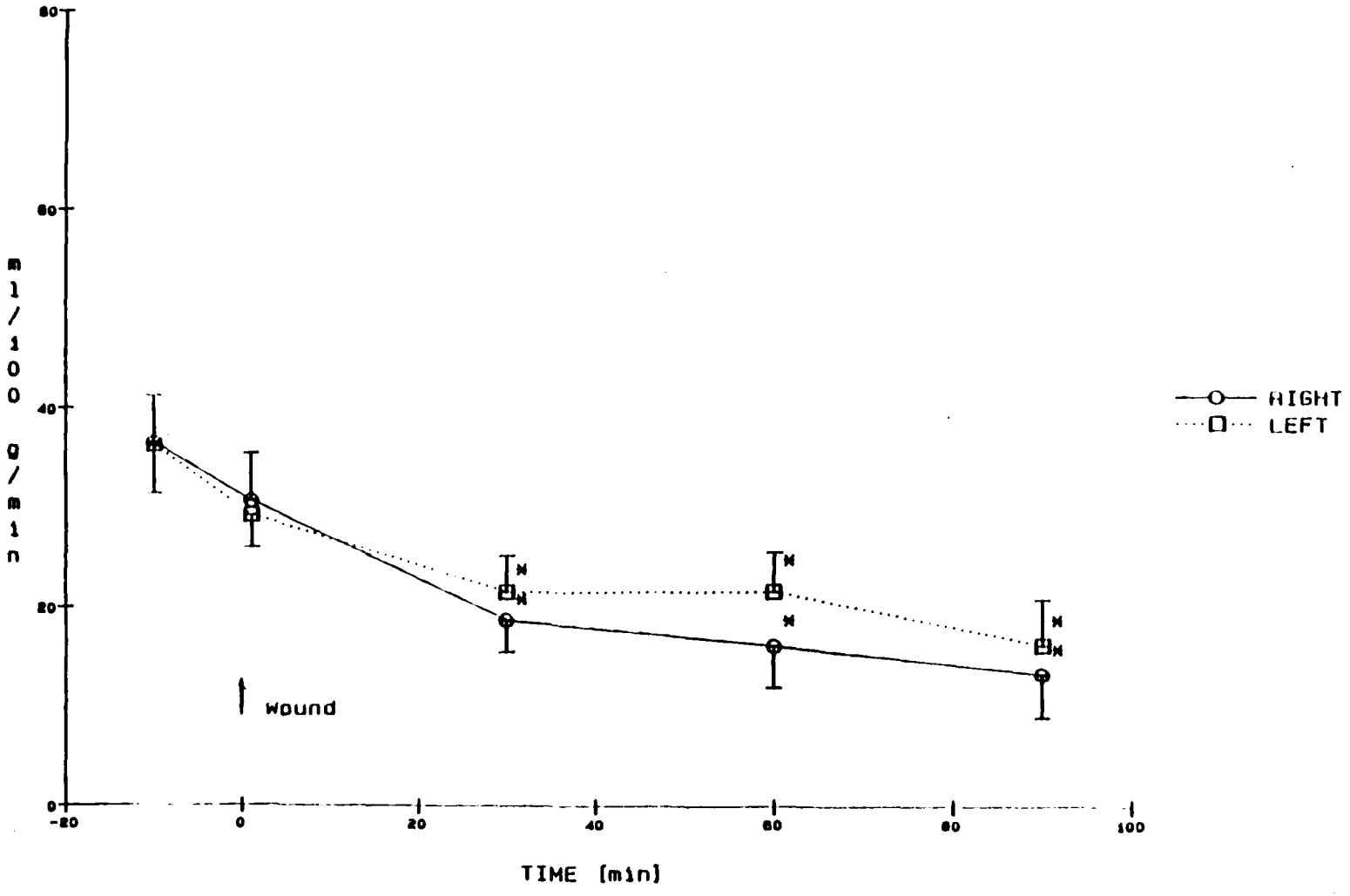
UPPER FRONTAL CBF - "COMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)
*-p<0.05 compared to control period (-10 min) (n=9)



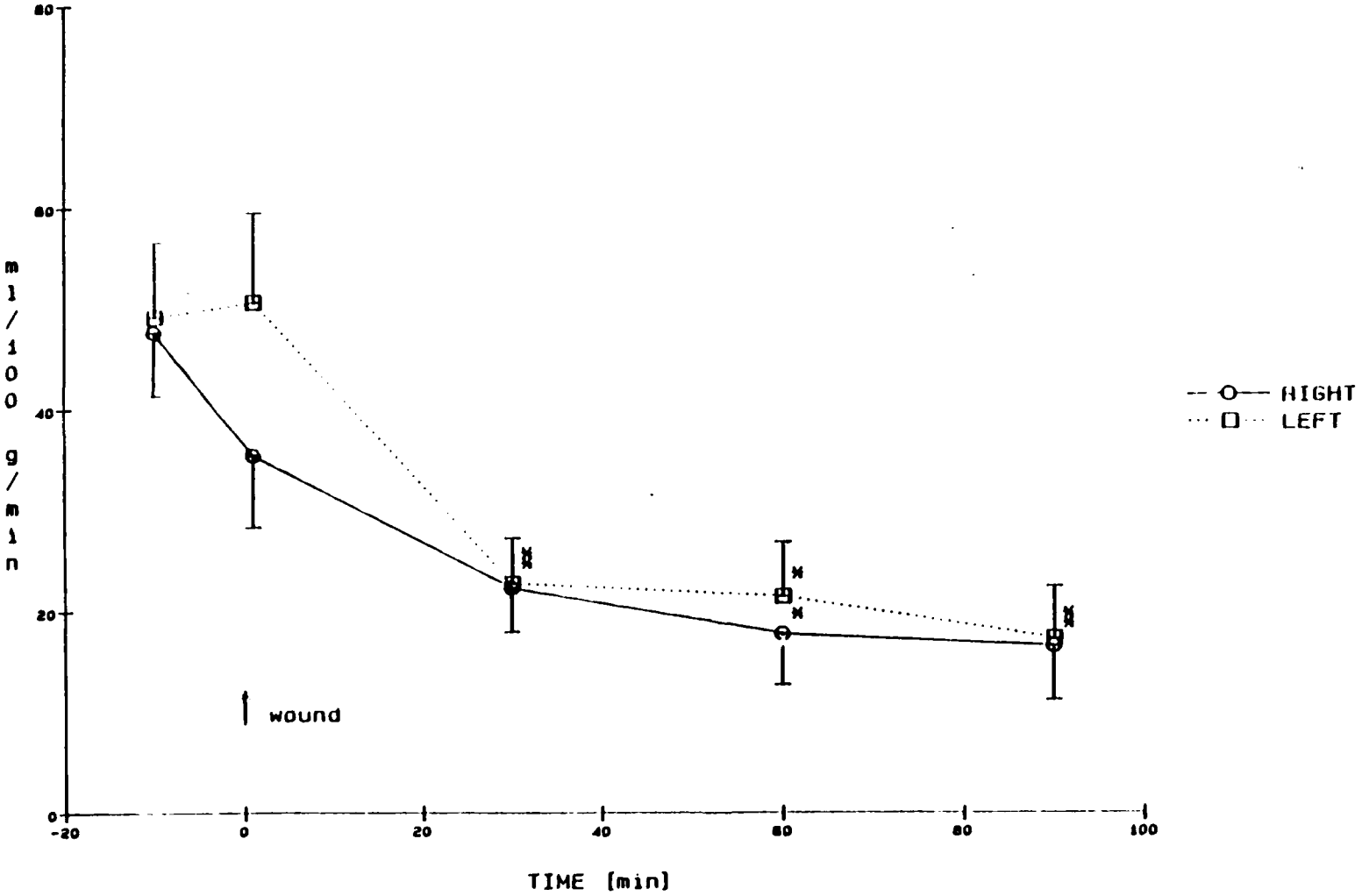
LOWER FRONTAL-TEMPORAL CBF - "COMPLICATED" CATS [0.9, 1.4 AND 2.4 J.]
M-p<0.05 compared to control period (-10 min) [n-9]

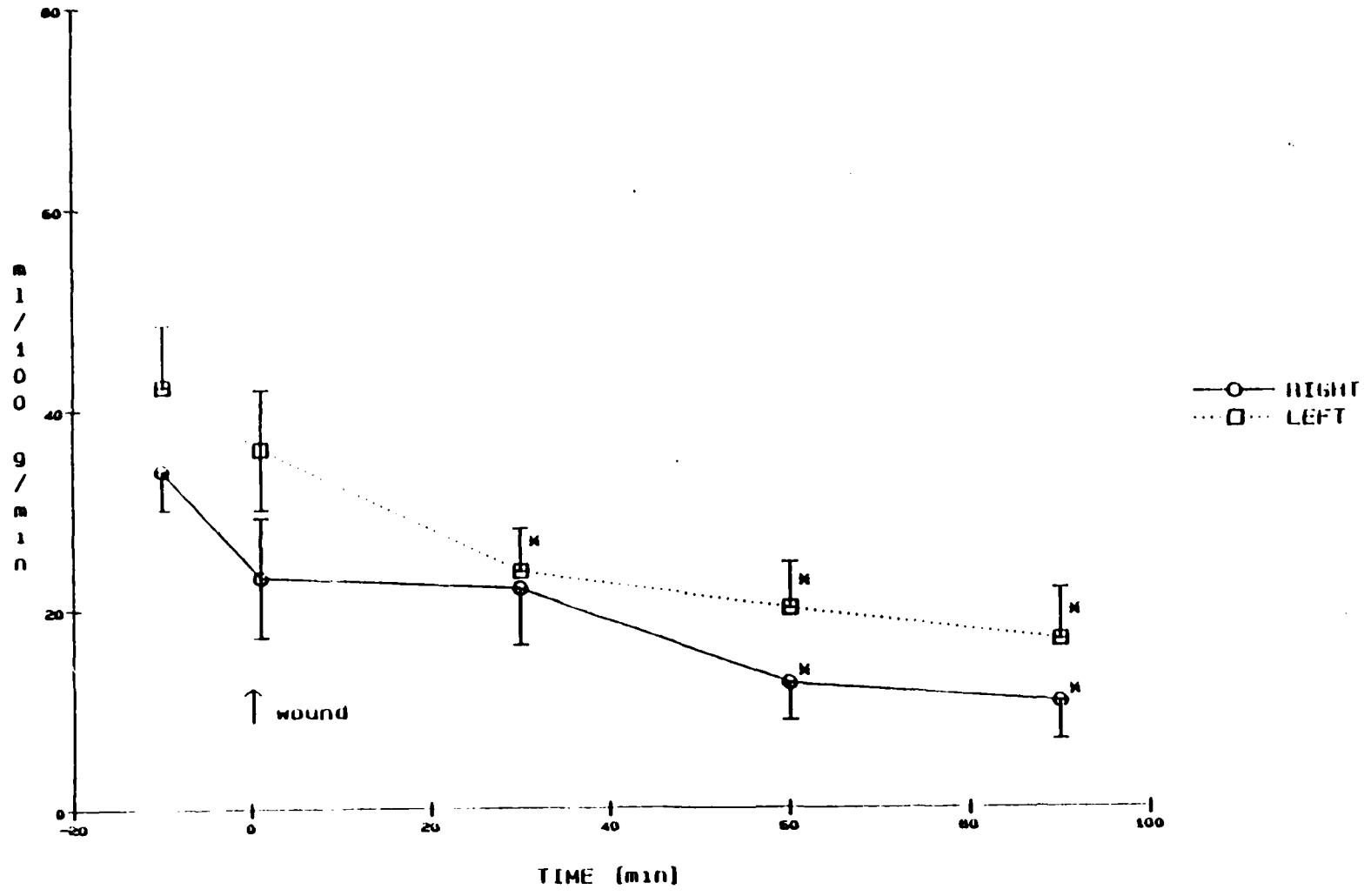



PARIETAL CBF - "COMPLICATED" CATS [0.9, 1.4, AND 2.4 µl.]
*-p<0.05 compared to control period (-10 min) [n=9]
RIGHT
LEFT
ml/100 g/min
TIME (min)
wound
-20
0
20
40
60
80
100

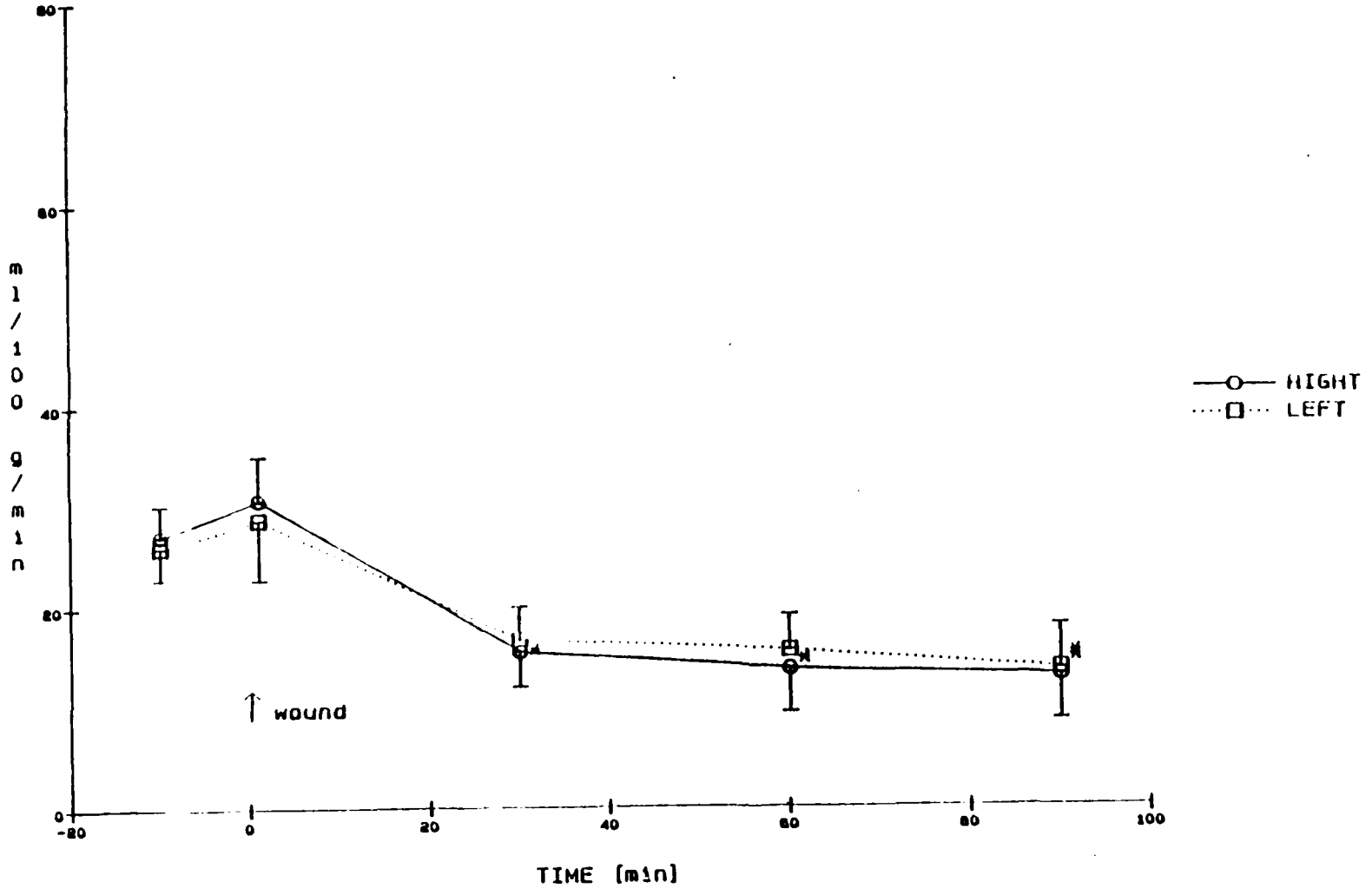

TEMPORAL CBF - "COMPLICATED" CATS (0.9, 1.4, AND 2.4 L.)
M-p<0.05 compared to control period (-10 min) (n=9)
ml/100 g/min
80
60
40
20
0
-20
0
20
40
60
80
100
TIME (min)
Wound
RIGHT
LEFT
M

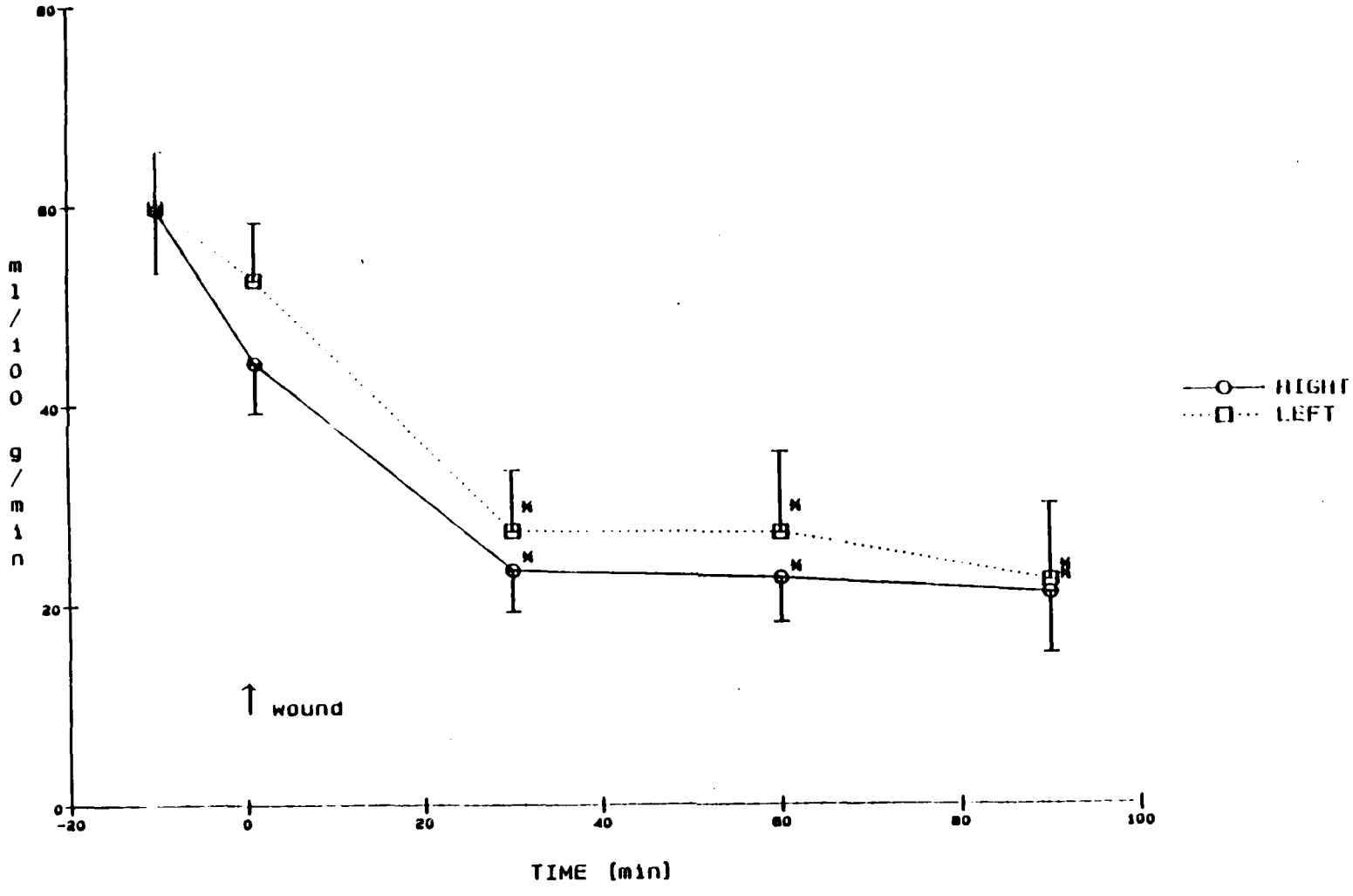
UPPER OCCIPITAL POLE CBF - "COMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)
*-p<0.05 compared to control period (-10 min) (n=9)



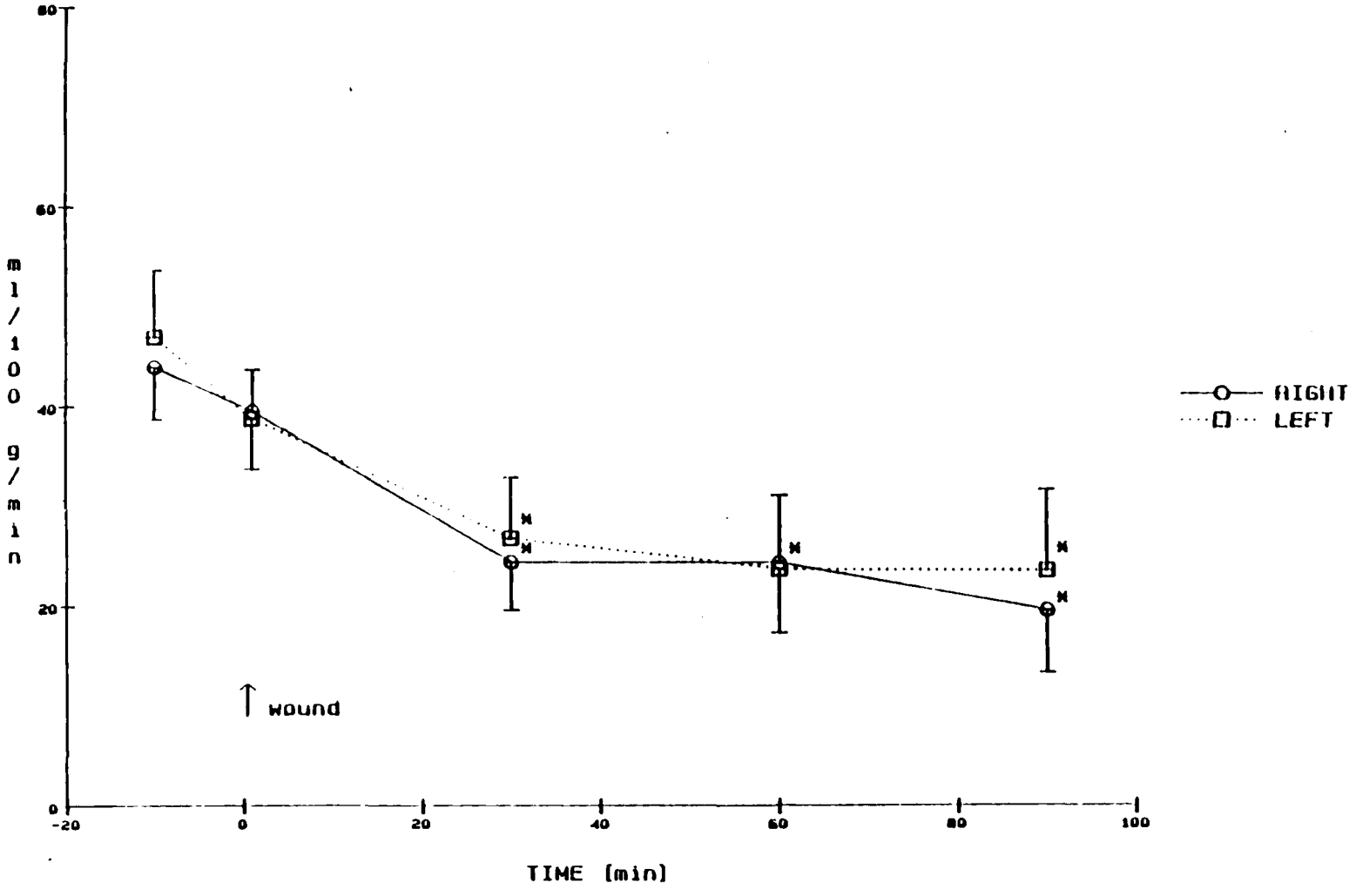

LOWER OCCIPITAL AREA CBF - "COMPLICATED" CATS (0.9, 14., AND 2.4 J.)
*-p<0.05 compared to control period (-10 min) (n=9)
ml/100 g/min
0
20
40
60
80
-60
0
20
40
60
80
100
wound
RIGHT
LEFT
TIME (min)

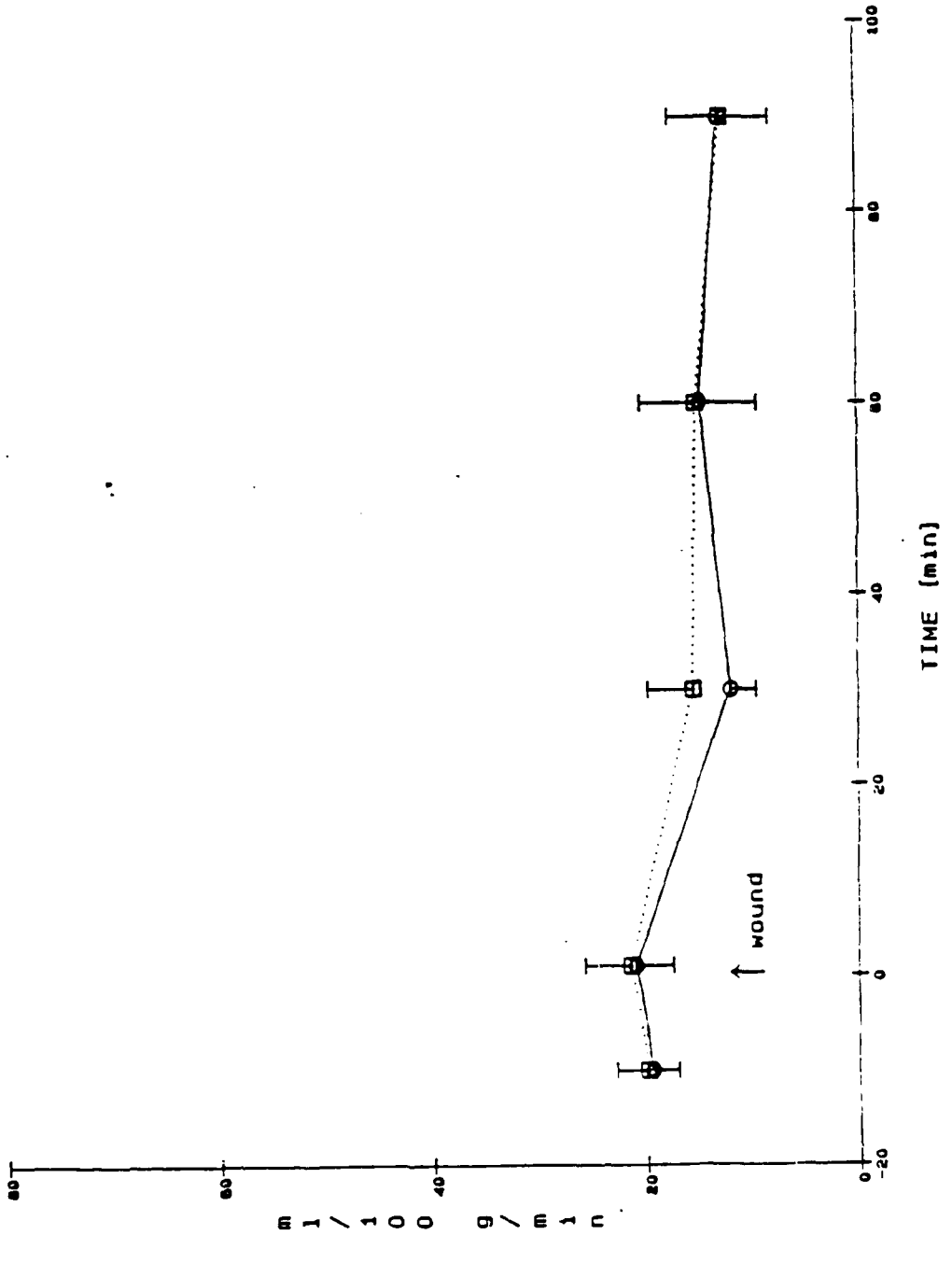
HIPPOCAMPUS CBF - "COMPLICATED" CATS [0.9, 1.4, AND 2.4 J.]
*-p<0.05 compared to control period (-10 min) [n=9]

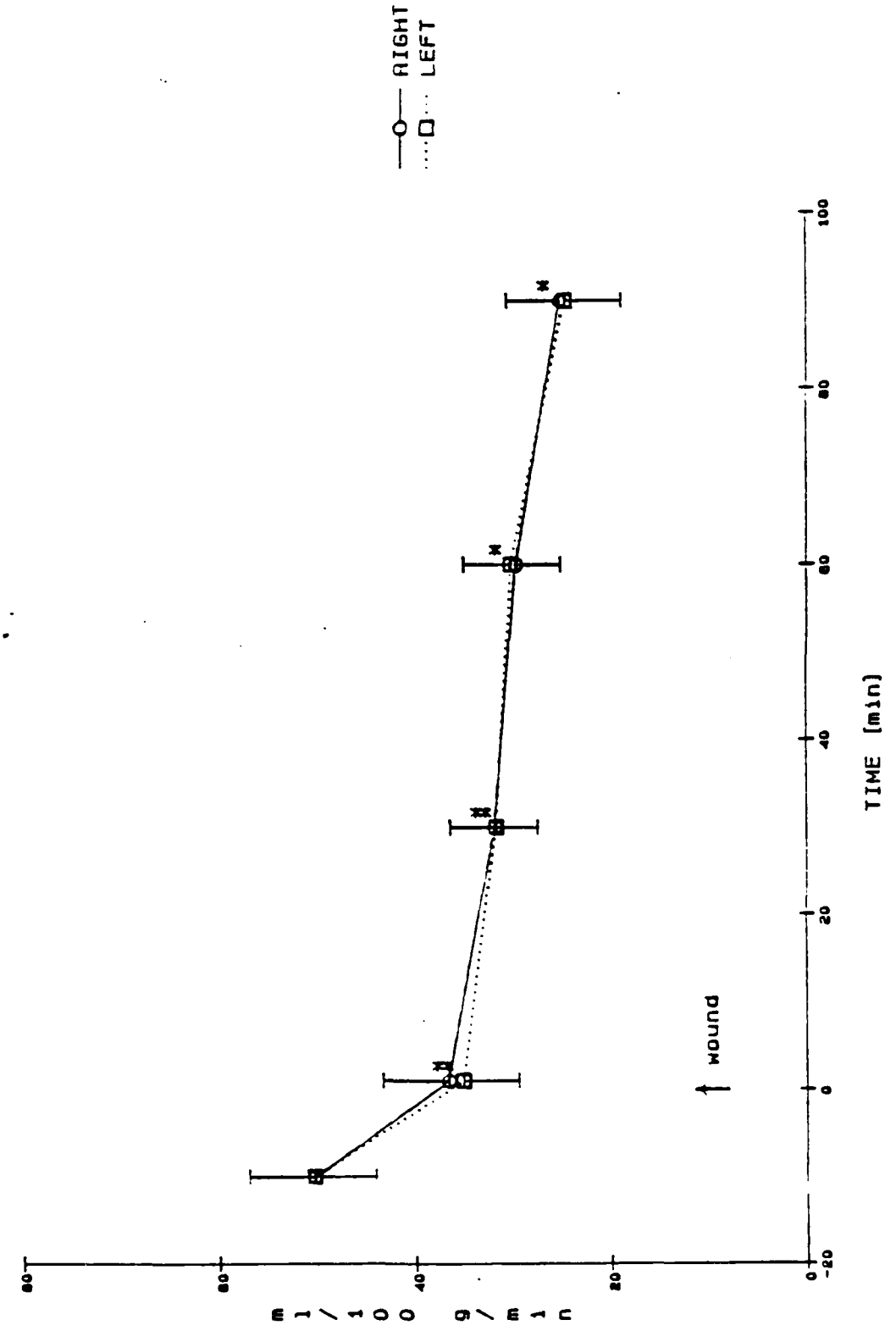


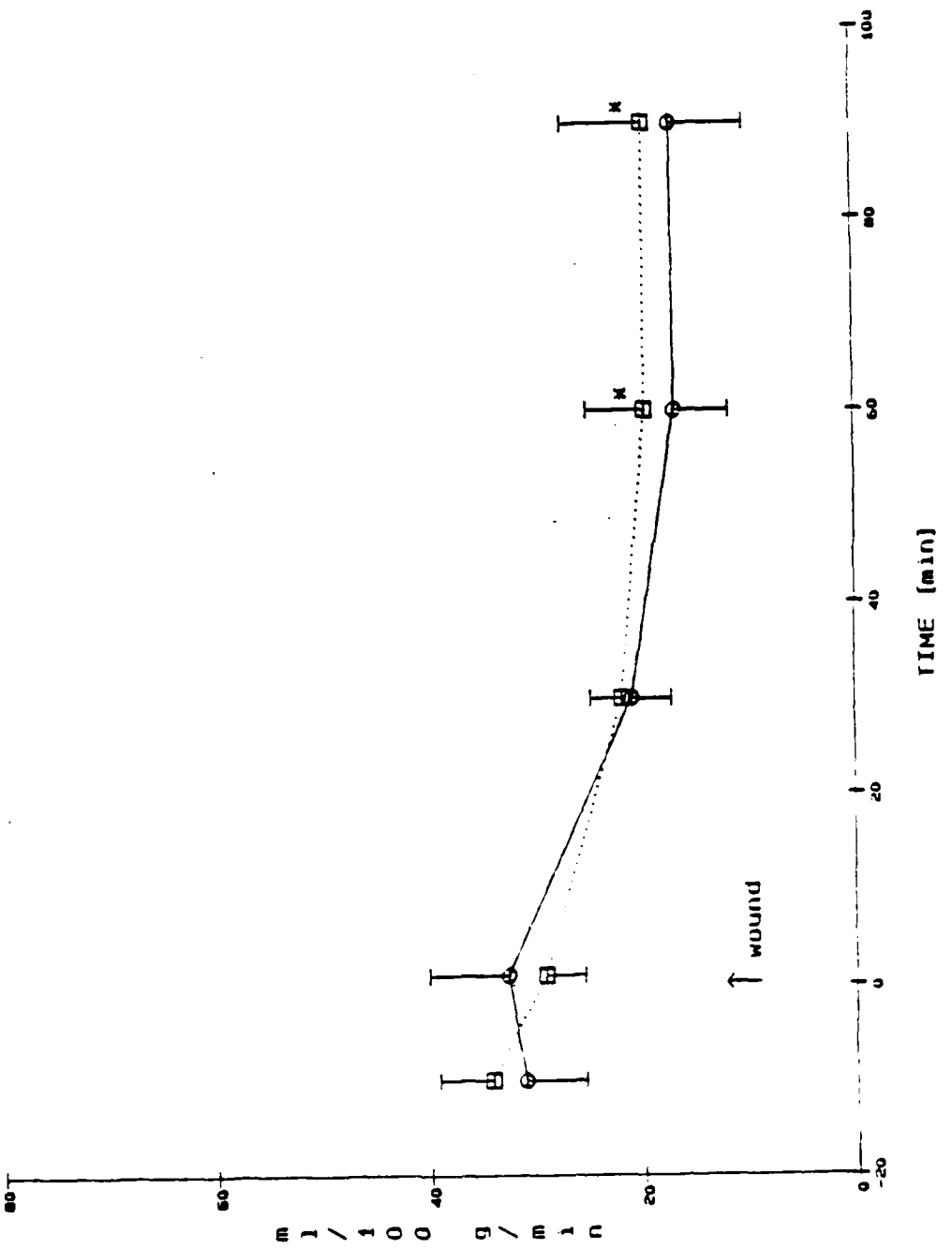

CAUDATE CBF - "COMPLICATED" CATS [0.9, 1.4, AND 2.4 J.]
*-p<0.05 compared to control period (-10 min) (n-9)
ml/100 g/min
80
60
40
20
0
-20
0
20
40
60
80
100
TIME (min)
wound
RIGHT
LEFT

THALAMUS CBF - "COMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)
*-p<0.05 compared to control period (-10 min) (n=9)

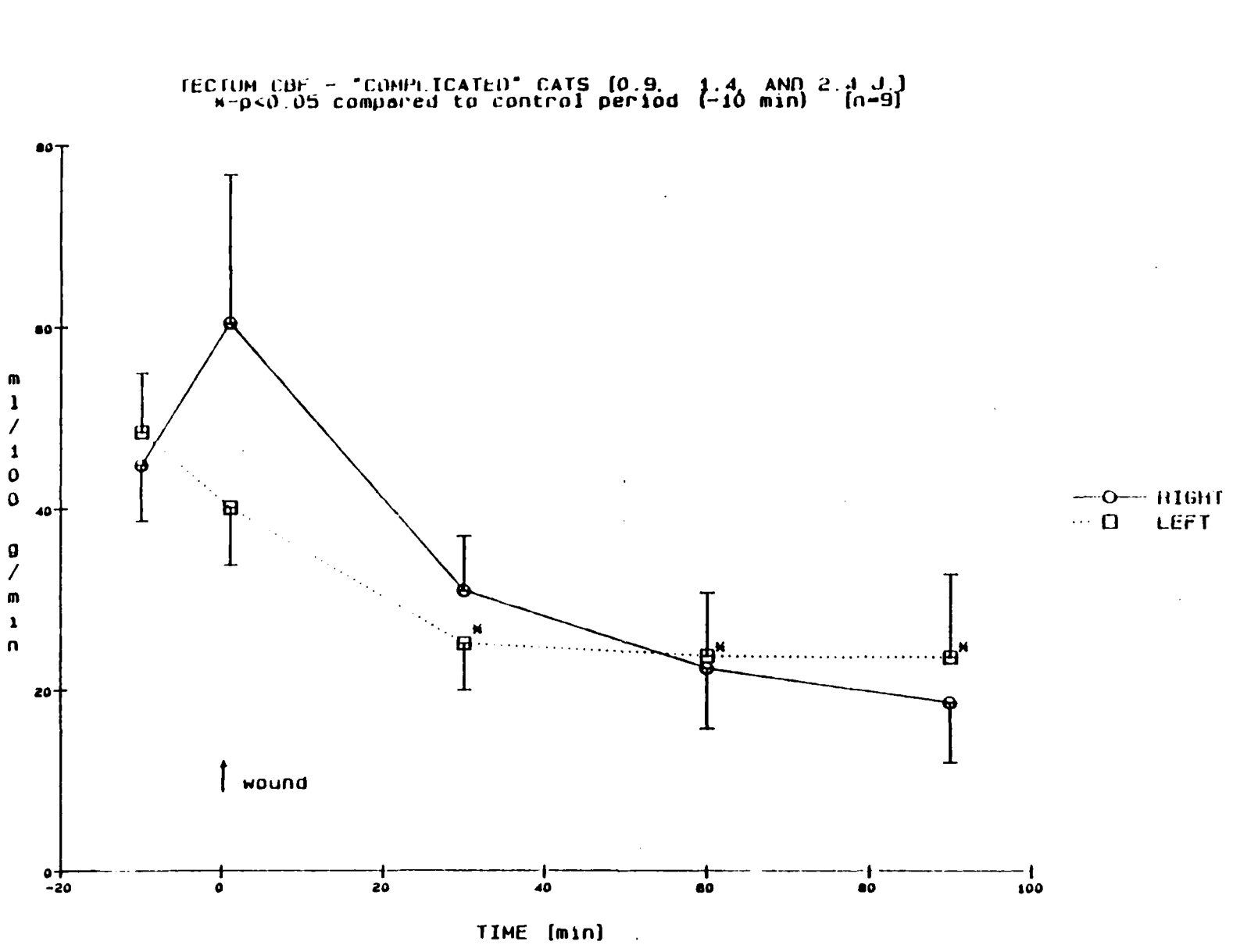



HYPOTHALAMUS CBF - "COMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)
(n-9)
RIGHT
LEFT
WOUND
ml/100 g/min
TIME (min)
0
20
40
60
80
-20
0
20
40
60
80
100

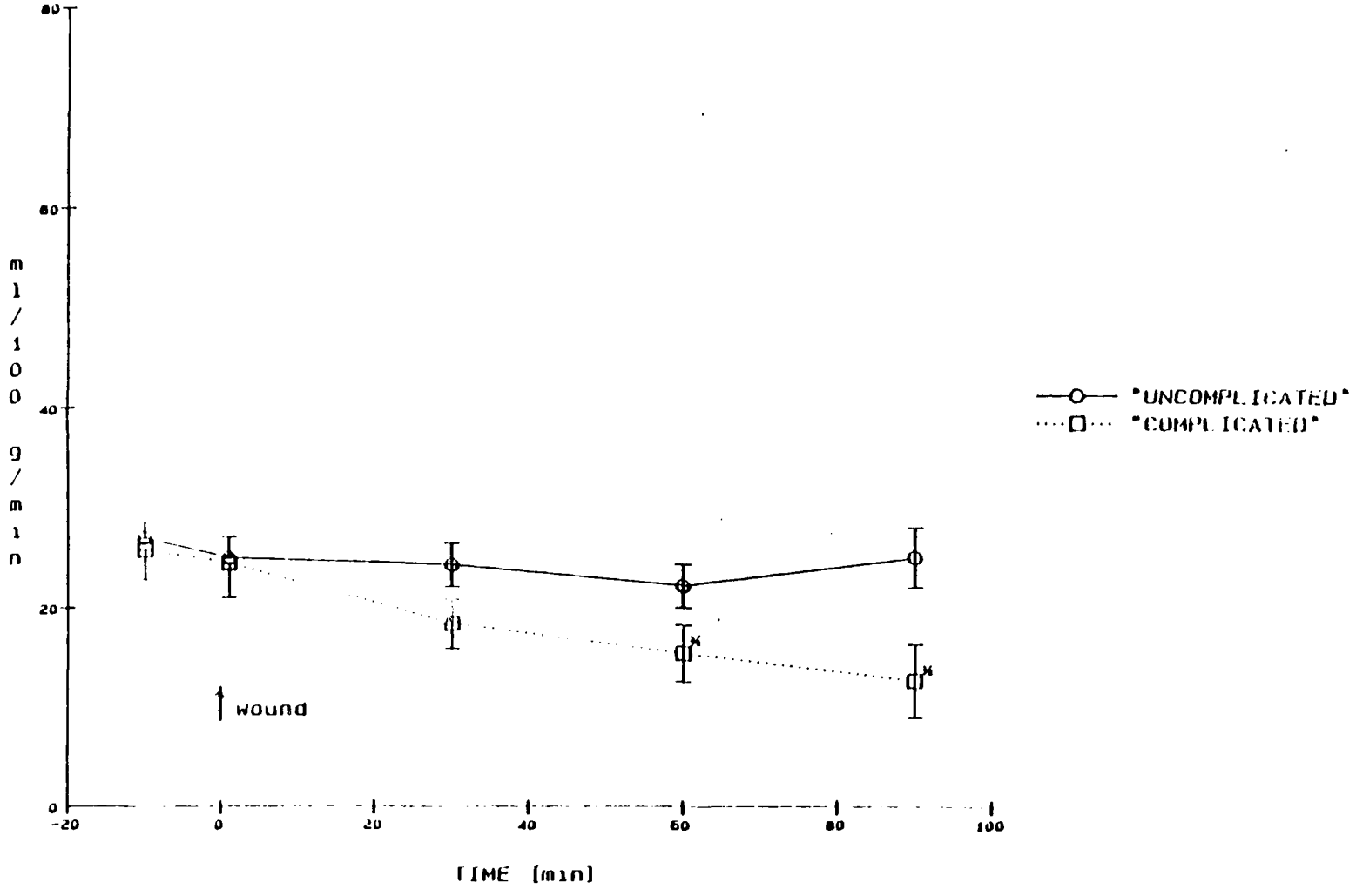

CEREBELLUM CBF - "COMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)
*-p<0.05 compared to control period (-10 min) (n=9)
RIGHT
LEFT
WOUND
ml/100 g/min
TIME (min)
0
20
40
60
80
100
-20



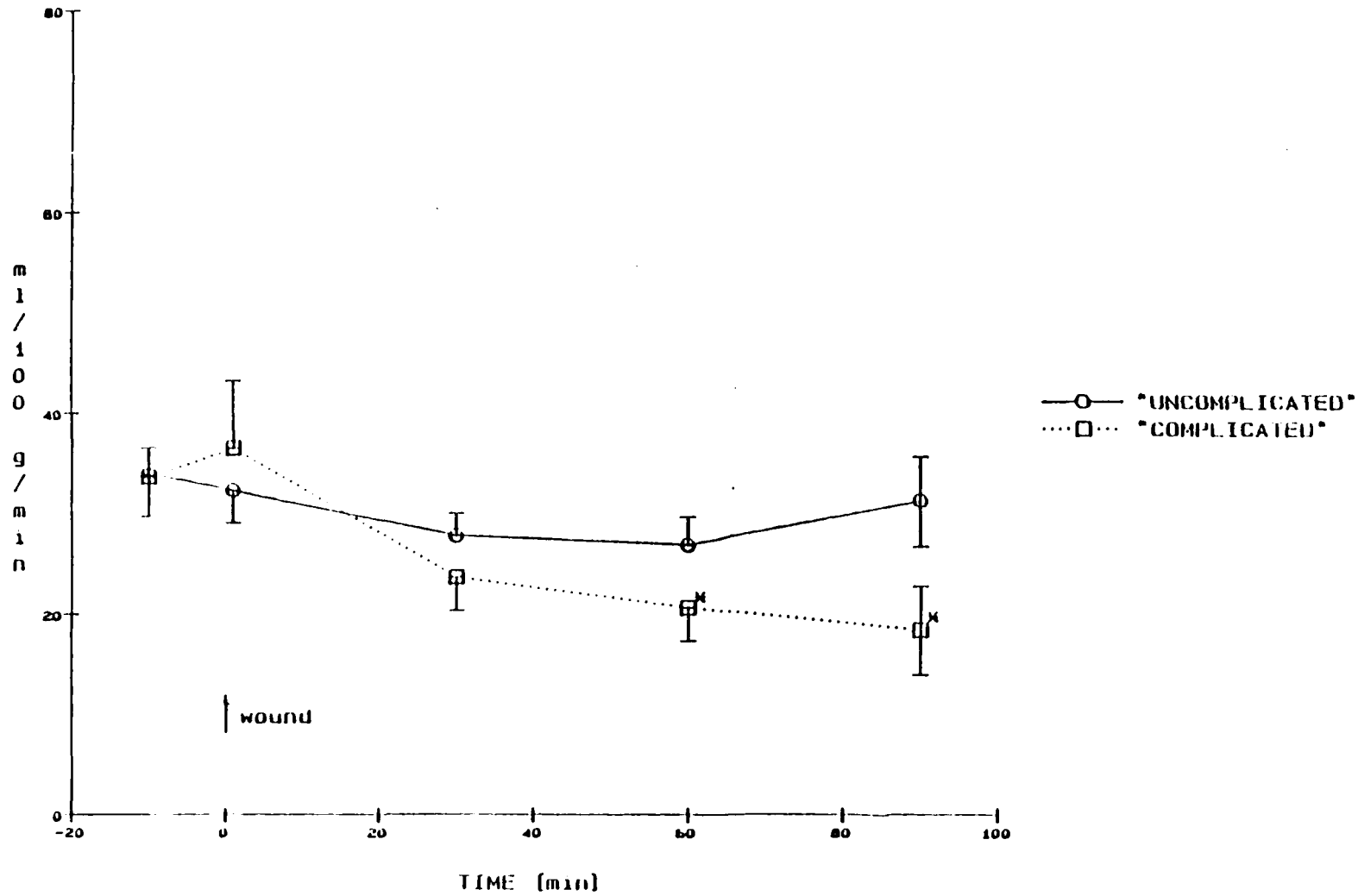
MESENCEPHALON CBF in "COMPLICATED" CATS (0.9, 1.4, AND 2.4 J.)
* p<0.05 compared to control period (-10 min) [n=9]


TECTUM CBF - "COMPLICATED" CATS (0.9, 1.4 AND 2.4 J.)
*-p<0.05 compared to control period (-10 min) (n=9)
ml/100 g/min
0
20
40
60
80
-20
0
20
40
60
80
100
TIME (min)
wound
RIGHT
LEFT
*
*
*

PONS CBF - CATS WOUNDED AT 0.9, 1.4, AND 2.4 J.
* p<0.05 compared to control period (-10 min)



MEDULLA CBF - CATS WOUNDED AT 0.9, 1.4, AND 2.4 J.
*-p<0.05 compared to control period (-10 min)



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